Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Water Quality

PART ONE of a Series entitled:
The Need for Stream Vegetated Buffers: What Does the Science Say?

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Introduction

Montana's vast landscape and water resources are critical to the economy, public welfare, and the quality of life of the state's local communities. Each year, development modifies these resources. Riparian areas and their associated wetlands, where water and land come together, are particularly sensitive to changes from development.

As a result of increasing pressures, representatives from local and state governments are discussing ways to protect streams, rivers, and their associated riparian areas from unplanned, sprawling development. One of the main tools available to local governments interested in protecting these resources is to set back structures and protect streamside buffers of native vegetation (hereafter referred to as "building setbacks with vegetative buffers"). In order to use this tool, decision makers and citizens alike must understand the science behind buffer widths.

The vegetated buffer is the "work horse" portion of this tool because it is the area that filters out pollutants, helps prevent unnatural erosion, works to minimize the impact of floods, sustains the food and habitat of fish and wildlife, and more. As a result, relevant scientific studies focus on the vegetated buffer portion of this tool. For more information on how building setbacks relate to vegetated buffers, see page 3.

Protecting water quality is one of the important functions of vegetated buffers. Consequently, this first report in a series summarizes the scientific recommendations underlying the vegetated buffer size needed to protect water quality. Two other reports have been developed in this series on other key elements of stream protection: fisheries and wildlife:

- *Part II: Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Fish and Aquatic Habitat;* and
- *Part III: Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Wildlife and Wildlife Habitat.*

Each of these reports is designed to explain the science behind one of the many functions provided by vegetated buffers found along streams. Other topics for this series are currently being considered because building setbacks and vegetated buffers should also consider floodplains and seasonal water levels, stream migration corridors, density of development adjacent to the riparian corridor, and other factors.

Building Setbacks and Vegetated Buffers

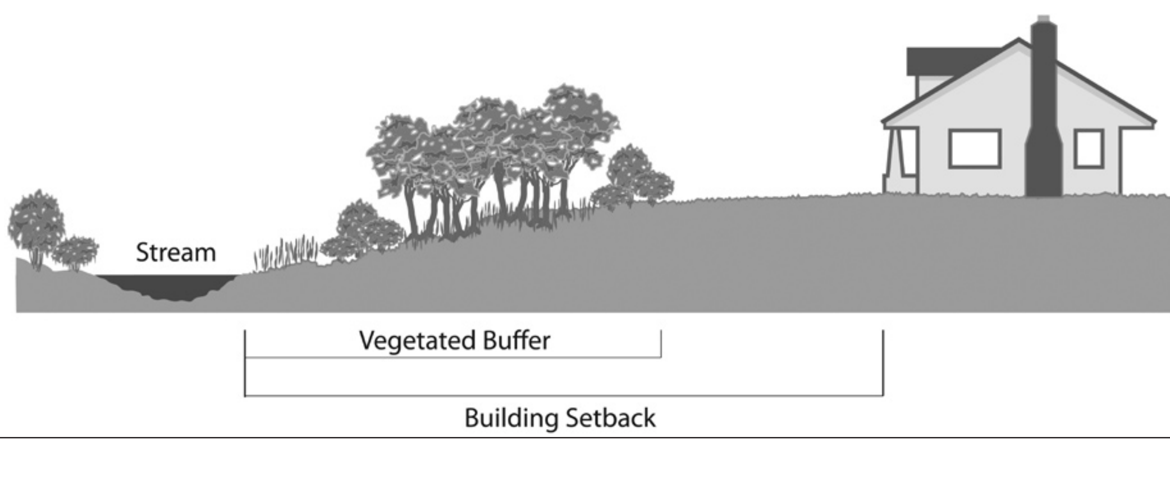
In order to understand setbacks and buffers, it is important to understand the following concepts:

Building setbacks or "no build areas" are the distance from a stream's ordinary high water mark to the area where new structures and other developments (such as highly polluting land uses—including roads, parking lots, and waste sites) are allowed.

Vegetated Buffers are not an additional area, but rather the portion of the building setback that is designated to remain undisturbed. These buffers are areas where all native vegetation, rocks, soil, and topography are maintained in their natural state, or enhanced by additional planting of native plants. Lawns should not be considered part of the vegetated buffer. With their shallow roots, lawns are not particularly effective at absorbing and retaining water, especially during heavy rains. Consequently, they do not significantly filter out water pollutants. They can also be a major source of fertilizers and pesticides—substances that should be prevented from entering our streams and rivers.

How much space should be placed between a building and a vegetated buffer? The building setback should be wide enough to prevent degradation of the vegetated buffer. As an example, most families use the area between their home and the vegetated buffer for lawns, play areas, swing sets, picnic tables, vegetable gardens, landscaping, etc. As a result, the building setback should extend at least 25–50 feet beyond the vegetated buffer (Wenger 1999). A smaller distance between a building and a vegetated buffer, such as 10 feet, will most likely guarantee degradation of the vegetated buffer. A greater distance between structures and a vegetated buffer is recommended if the:

- River has a history of meandering; the setbacks should ensure that people and homes will not unwittingly be placed too close to the river's edge, in harm's way.
- Vegetated buffer is narrower than scientific studies recommend; a deeper building setback can help protect water quality, fisheries, and aquatic habitat.
- Land is sloped and runoff is directed toward the stream (the steeper the slope, the wider a buffer or setback should be)
- Land use is intensive (crops, construction, development)
- Soils are erodible
- Land drains a large area
- Aesthetic or economic values need to be preserved
- Wildlife habitat needs to be protected
- Landowners desire more privacy



Vegetated Buffers and Clean Water

All Montanans depend upon clean water. Vegetated buffers along streams break down and/or retain nutrients, salts, sediments, chemical pesticides, and organic wastes. Buffers also act like giant sponges to filter and reduce the amount of pollutants that enter streams, groundwater, and—ultimately—drinking water, in runoff originating from sources such as city streets, lawns, construction sites, and agricultural fields.

Examples of common vegetated buffer restrictions include:

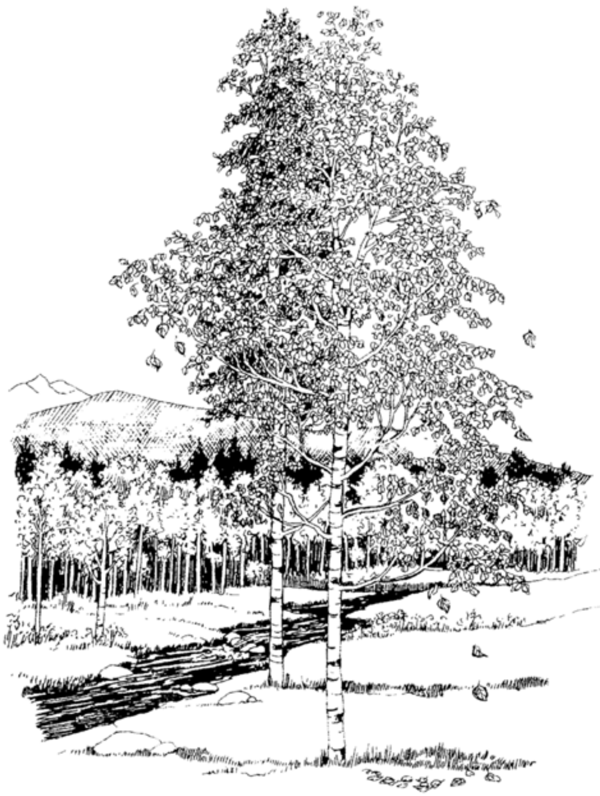
- Minimizing removal of native vegetation;
- Using native vegetation in plantings and restoration;
- Prohibiting non-native plants (including lawns);
- Prohibiting the use of pesticides and fertilizers;
- Avoiding use of heavy equipment that compacts soil; and
- Restricting mowing and managing grazing so as to avoid loss of riparian vegetation.

It should be noted that the ability of vegetated buffers to provide adequate water quality protection depends upon the slope, vegetation, floodplains, soils, and other similar factors. The following descriptions explain why these factors influence how effective a vegetated buffer is in protecting water quality:

Steep Slopes. From a water quality perspective, the most effective buffers are flat. Scientific research shows that the width of buffers should be increased when slopes are steeper, to allow more opportunity for the buffer to capture pollutants (Castelle et al 1994; Fischer et al 2000; Mayer et al 2005; Knutson and Naef 1997; and Wenger 1999). The greater the slope, the faster water flows over the surface. Researchers have noted that very steep slopes cannot effectively remove contaminants, though there is debate over what constitutes a steep slope, with ranges suggested between 10% and 40%. One model suggests that slopes over 25% should not count towards a buffer (Wenger 1999).

Vegetation. Natural vegetated buffers are important to water quality, because the longer runoff is detained in a buffer, the fewer pollutants will enter the stream. Physically, plants act as a barrier, slowing down water flow, giving sediments and other contaminants time to settle out of runoff, and allowing more water to move into the soil. Plant roots trap sediments and other contaminants in shallow groundwater, take up nutrients, hold banks in place, and prevent erosion. Runoff that seeps into shallow groundwater increases groundwater recharge and temporarily stores and slowly discharges precipitation and snowmelt to surface waters over a longer period of time.

Although vegetated buffers with woody plant species (trees and shrubs) and native grasses are both effective at trapping pollutants, those with woody plants provide the most effective water quality protection for several reasons. First, by providing a canopy, trees and shrubs reduce the velocity of raindrops and lessen runoff and soil erosion. Trees and shrubs also have longer, more complex root systems, which increase their ability to absorb nutrients and curtail erosion. Overhanging branches provide shade that reduces stream temperatures. Litter (leaves and organic debris) from trees and shrubs also increase the infiltration and pollution-absorbing ability of soil. And finally, trees and shrubs provide the most diverse fish and wildlife habitat in Montana, providing cover, nesting sites, and food. Native grasses also have complex root systems—especially compared



to the root systems of lawn grass—but they are not as deep-rooted as trees and shrubs.

As stated above, lawns—with their shallow roots—are not particularly effective at absorbing and retaining water, especially during heavy rains. Consequently, they do not significantly filter out water pollutants. Lawns can also be a major source of fertilizers and pesticides—substances that need to be prevented from entering our streams and rivers.

Surfaces without vegetation—including parking lots, compacted or paved roads, and other impervious surfaces—reduce the filtering capability of buffer areas, increase surface erosion, and lead to higher and faster storm flows in streams. As a result, restrictions on impervious surfaces should be considered in order to ensure that buffers are effective.

Floodplains. Because much pollution can enter streams during storm events caused by snowmelt or heavy rainstorms, protection of a stream or river's floodplain is important. Floodplains covered with native vegetation can significantly remove contaminants, minimize damage from floods, and reduce the amount of unnatural erosion that takes place. For these reasons, it is recommended that vegetated buffers encompass the entire floodplain whenever possible (Wenger 1999). This recommendation is particularly important in Montana's valleys, where streams and rivers meander.

Soils. Different soils have different abilities to filter out sediment and pollutants. Consequently, activities that compact soils or increase erosion (such as vegetation removal) should be avoided in vegetated buffers. The speed with which water and dissolved substances percolate through the soil depends upon the amount of organic material and the size of the spaces between the grains of soil. As an example, in fine clay soils, pollutants may take months or years to move into streams and groundwater. In porous soils (e.g. with more sand and gravel), pollutants can flow almost directly into streams or groundwater.

Contaminants Impacting Water Quality

Many of the substances covered in this report can degrade water quality. Vegetated stream buffers are an important tool that local governments can use to filter out these pollutants. Tables II and III summarize the information from scientific studies that tested how stream vegetated buffers filtered out the following contaminants (which are listed in alphabetical order, and not in order of importance):

Ammonium (NH_4) is a form of nitrogen (*see Nitrogen below*) found in human and animal waste (hence in sewage and septic field leakage) and in some fertilizers. It is toxic to fish and many other

Lawns—with their shallow roots—do not significantly filter out water pollutants. They can also be a source of fertilizers and pesticides, substances that should not enter streams and rivers. Montana Dept. of Natural Resources and Conservation photo library.

forms of stream life. Like all forms of nitrogen, ammonia can contribute to eutrophication (over-fertilization) of lakes, wetlands, and slow-moving streams (*see Nutrients below*).

Fecal coliform bacteria are found in the fecal material of humans or other animals and are used as an indicator of the likely presence of bacteria and viruses that cause a wide range of diseases. Sources of such bacteria and viruses include leaking sewer pipes, sewer overflows, failing septic systems, and areas where concentrations of animals are found, such as animal feedlots, city parks frequented by dogs, and areas with colonial nesting birds. The higher the levels of fecal coliform bacteria in water the greater the risk to human health because of the many waterborne pathogenic diseases associated with bodily wastes.

Heavy metals, such as lead, mercury, cadmium, copper, and zinc, occur naturally in streams and soils. However, many human activities increase the movement of these substances from land into water, raising the concentration of these metals to levels that are toxic to aquatic life. At very high levels, such metals may quickly kill aquatic life. Even at fairly low levels, metals may gradually accumulate in the liver or kidneys of animals, causing failure of these organs. The main sources of these contaminants are industrial and consumer waste, including power plant and other industrial emissions, old mining operations, run-

off from roads and parking areas, and fertilizers.

Nitrogen (N) is an essential nutrient for all life. Under natural conditions it is often in short supply, limiting plant growth. However, many kinds of human activity increase availability of nitrogen, stimulating growth of plants. In water, excess nitrogen is a pollutant that can cause eutrophication (over-fertilization) (*see Nutrients below*) in surface water and contamination of groundwater. As a drinking water pollutant, nitrogen is particularly dangerous for infants. Streams receive nitrogen from sources such as fertilizers, animal wastes, leaking sewer lines and septic systems, and runoff from highways. The U.S. Environmental Protection Agency considers nitrogen one of the "top stressors in aquatic ecosystems" (Mayer, et al 2005). Nitrogen occurs in many forms, including nitrates, nitrites, ammonium, and particulate nitrogen.

Nitrates (NO_3) and Nitrites (NO_2) are forms of nitrogen that occur in fertilizers, animal wastes, septic tanks, municipal sewage treatment systems, and decaying plants (see *Nitrogen above*). Nitrates/nitrites can move quickly through the soil and into groundwater and surface water. However, nitrate/nitrite levels in shallow groundwater can be reduced before reaching surface water in two main ways: (1) uptake by the roots of plants in vegetated buffers, or (2) use by bacteria that live in water-saturated soils which convert nitrates/nitrites to harmless nitrogen gas (a process called denitrification).

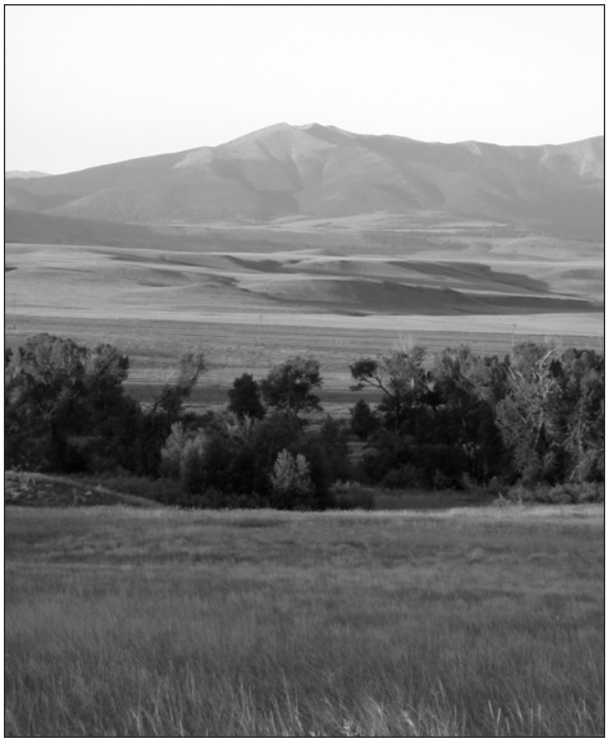
Nutrients are substances that are essential to life and include certain forms of nitrogen (*see above*) and phosphorus (*see below*). Increases in availability of nutrients may stimulate additional growth of plants. In water, excess nutrients increase the rate of eutrophication of lakes and slow-moving streams. Eutrophication can stimulate abundant plant growth in water bodies, which can lead to toxic algae blooms, excessive growth of nuisance aquatic plants, the depletion of oxygen in water, and—ultimately—the death of fish and other organisms. Hence at excessive levels, nutrients are considered water pollutants.

Pesticides, including both herbicides and insecticides, are designed to be toxic. The main sources for these chemicals include spraying of crops, weed-infested rangelands, lawns, and ornamental plants. At high enough concentrations in streams, pesticides may kill stream life outright, or weaken organisms so they die more readily from 'natural causes.' Pesticides also pose a risk to human health, especially those that biomagnify in the food chain. Biomagnification refers to the process where certain substances increase in concentration as they move from one link in the food chain to another.

Phosphorus (P) is an essential nutrient for plant growth that is found naturally in soils and streams, but exists in much higher levels in fertilizers and in human and other animal waste. It enters streams in waste water or in runoff polluted with fertilizers or animal wastes, including from leaking sewer pipes or septic drain fields. Stream vegetated buffers are typically effective at short-term control of phosphorus that is bound to sediment particles—they are *less* effective at (1) filtering out phosphorus that is dissolved in water, or (2) providing long-term storage of phosphorus (Wenger 1999). Increased levels of phosphorus can contribute to eutrophication (see *Nutrients* above).

Sediments are a common type of pollutant found in streams and rivers. Sediments come from a variety of sources, including natural and human-driven stream bank erosion, agricultural fields, exposed earth at construction sites and on dirt roads, and other activities that remove vegetation and expose soil. Excess sediment has numerous impacts, including degrading municipal water supplies and, as a result, increasing water

treatment costs and/or posing a threat to human heath when treatment is made less effective. It can also degrade habitat for fish and the aquatic life that they eat and can clog drainage ditches, stream channels, water intakes, and reservoirs.



About This Report—Methods Used

This report summarizes the recommendations of 77 scientific studies that tested how various stream vegetated buffers protected water quality (*see Appendix I*). These scientific studies were reviewed by the authors of 5 review publications. Please note that the information in this report was taken from the text and tables of 5 review publications—and that the original studies were not reviewed in this report. The 5 review publications are:

- Castelle, A.J., A. W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements — a review. J. Environ. Qual. 23: 878–882.
- Fischer, R.A., C.O. Martin, and J.C. Fischenich. 2000. Improving riparian buffer strips and corridors for water quality and wildlife. International Conference on Riparian Ecology and Management in Multi-Land Use Watersheds. American Water Resources Association. August 2000. 7 pp.
- Knutson, K.L. and V.L. Naef. 1997. Management recommendations for Washington's priority habitats: riparian. Wash. Dept. Fish and Wildlife, Olympia, WA. 181 pp.
- Mayer, P.M., Steven K. Reynolds, Jr., Timothy J. Caneld. 2005. Riparian buffer width, vegetated cover, and nitrogen removal effectiveness: a review of current science and regulations. U.S. Environmental Protection Agency, EPA/600/R-05/118, National Risk Management Research Laboratory, Ada, OK. 28 pp.
- Wenger, S.J. 1999. A review of the scientific literature on riparian buffer width, extent and vegetation. Athens: Institute of Ecology Office for Public Service and Outreach, University of Georgia. 59 pp.

Appendix II contains the original references cited in the 5 review publications described above, allowing individuals using Appendix I to see the full title of all original references, as well as have sufficient information to access all references, if necessary.

Summary of Scientific Recommendations

All Montanans depend upon clean water—and streamside vegetated buffers play an important role in water quality protection. These areas break down and hold nutrients, chemical pesticides, salts, sediments, and organic wastes. They reduce the amount of pollution that enters streams, rivers, groundwater, and—ultimately—drinking

water, in runoff originating from sources such as city streets, leaking sewer lines and septic systems, lawns, construction sites, and agricultural fields. As a result:

In order to protect the water quality of streams, scientific studies generally recommend that at least a 100-foot (30-meter) vegetated buffer be maintained. Steeper slopes and other local factors may require larger vegetated buffers. A minimum of a 50-foot (15-meter) buffer may be sufficient to protect certain aspects of water quality. However, for significant removal of nitrates, sediments, and pathogenic bacteria, at least 100 feet is recommended.

This recommendation is drawn from the conclusions of the 5 publications that reviewed a total of 77 separate scientific studies on water quality and stream vegetated buffers. Specific conclusions and recommendations by the 5 review publication authors are quoted in Table I.

This conclusion is also supported by the State of Montana's Nonpoint Source Management Plan, which was approved by the U.S. Environmental Protection Agency (EPA) in July 2007. It states that a "buffer of at least 100 feet is recommended for water quality protection. . . . Minimum widths for buffers should be 50 feet for low order headwaters streams, with expansion to as much as 200 feet or more for larger streams." Montana's Nonpoint Source Management Plan identifies locally-adopted water body setbacks as important "Best Management Practices" to protect and improve water quality from nonpoint source pollution. Nonpoint sources of pollution in urban areas include parking lots, streets, and roads where stormwater picks up oils, grease, metals, dirt,

Table I. A summary of the specific conclusions and recommendations of 5 review articles on vegetated buffer size and water quality protection. All authors emphasized that water quality protection depends on the slopes, soils, vegetation, floodplains, and similar factors.

Castelle et al 1994	"Based on existing literature, buffers necessary to protect wetlands and streams should be a minimum of 15 to 30 meters in width" (50–100 feet).
	Buffers less than 10 meters (33 feet) "provide little protection of aquatic resources under most circumstances."
Fischer et al 2000	Concluded that "most buffer width recommendations for improving water quality tend to be between 10 and 30 m" (33–100 feet).
Knutson and Naef 1997	Concluded that scientific studies indicated that vegetated buffers to protect water quality should be between 24 and 42 meters (78–138 feet).
Mayer et al 2005	Concluded that "wider buffers (>50 m) [167 feet] more consistently removed significant portions of nitrogen entering a riparian zone."
	[W]hile some narrow buffers (1–15 m) [3–50 feet] removed significant proportions of nitrogen, narrow buffers actually contributed to nitrogen loads in riparian zones in some cases."
Wenger 1999	To protect water quality overall, "a 100 ft [30 meter] fixed-width riparian buffer is recommended for local governments that find it impractical to administer a variable-width buffer."
	For long-term sediment control and short-term phosphorus control, a "30 m (100 ft) buffer is sufficiently wide to trap sediments under most circumstances."
	For nitrogen control, in "most cases 30 m (100 ft) buffers should provide good control, and 15 m (50 ft) should be sufficient under many conditions."
	For pesticide and heavy metal control, "the width is unclear from the existing research," with 15 meters (50 feet) seen as a bare minimum, and 50 meters (164 feet) shown to filter out much of two specific pesticides.

salts, and other toxic materials. In areas where crops are grown or in areas with landscaping (including grassy areas of residential lawns and city parks), irrigation and rainfall can carry soil, pesticides, fertilizers, herbicides, and insecticides to surface water and groundwater (Montana Department of Environmental Quality, 2007).

Several additional recommendations are worth noting:

- "The greater the minimum buffer width, the greater the safety margin in terms of water quality and habitat protection." (Wenger 1999)

- "Removal of riparian vegetation, drainage of wetlands and development of floodplains leads to larger magnitude floods that cause greater damage to property." (Wenger 1999)

- "To provide maximum protection from floods and maximum storage of flood waters, a buffer should include the entire floodplain. Short of this, the buffer should be as wide as possible and include all adjacent wetlands." (Wenger 1999)

- "Riparian buffers are especially important along the smaller headwater streams which make up the majority of stream miles in any basin." (Wenger 1999)

- "It is very important that buffers be continuous along streams. Gaps, crossings, or other breaks in the riparian buffer allow direct access of surface flow to the stream, compromising the effectiveness of the system." (Wenger 1999)

- "[E]xtensive experimental support for buffer zones <10 meters [33 feet] . . . is lacking." (Mayer et al 2005).

In order to better understand the range of scientific studies that went into the above conclusions, Appendix I contains study-specific information for all 77 scientific studies reviewed. It should be noted that many of these studies underwent extensive peer review before they were published in a peer-reviewed journal or report of a scientific government agency. The summarized studies show a range of buffer widths, because the ability of buffers to trap pollutants is affected by slope, soil type, vegetation type and density, climate, floodplains, and many more factors. It would be very costly to duplicate these studies in every situation; hence the recommendations given here are intended to be protective in most situations, based on the findings of a wide range of studies. If localized information on area conditions is available (vegetation maps, floodplain maps, etc.), this information can also be used to determine vegetated buffer sizes, ensuring that these buffers more accurately fit local conditions.

And finally, because Appendix I contains a lot of detailed information, which can be difficult to interpret, we created Table II. Table II is designed to organize the findings of the 77 scientific studies by activity (erosion and flood control) or type of pollutant (nutrients, ammonia, fecal coliform, nitrates, nitrogen, pesticides, phosphorus, and sediment)—giving readers a snapshot of the vegetated buffer width needed to control individual pollutants. As explained below, we did not use all scientific studies to create Table II—just those that reduced a specific water pollutant by 80% or more. The 80% threshold was chosen as a reasonable goal for nonpoint source pollution control; it may be insufficient for some pollutants, such as ammonia and fecal coliform. It is interesting to note that if pollutants are removed by 80% or more, it appears that stream vegetated buffers should be at least 130 feet, and not 100 feet, as recommended by the authors of the 5 review articles featured in this report.

Table II. Summary of stream vegetated buffer widths recommended to protect water quality. This table was compiled using information from the scientific studies reported in Appendix I below, as reported in the 5 review articles featured in this report. This table gives the average vegetated buffer width recommended to filter out approximately 80% of the following pollutants: ammonia, fecal coliform, nitrates, nitrogen, pesticides, phosphorus, and sediment. Desired buffer width was calculated by averaging the recommended buffer width for all studies that met or exceeded the 80% removal criteria. Where studies reported a range of values, the median of that range was used to calculate the average (mean) buffer width. In addition to an average buffer width, the range of buffer sizes from all studies meeting or exceeding the 80% reduction level is provided. Please note that nutrient reduction studies were treated slightly differently: because reviewed nutrient studies did not include a figure (e.g. 80% threshold) for the amount of pollution removed, the average buffer width for this pollutant was calculated using all scientific studies reviewed (12 studies total).

Type of Water Pollution	**Average Stream Buffer Width**	**Number of Studies Used in Calculating Desired Buffer Width**
Erosion control	100-year floodplain, but at least 100 feet	Review article conclusion (Wenger 1999)
Flood control, includes channel migration ability	100-year floodplain	Review article conclusion (Castelle et al 1994)
Nutrient	100 feet (range 33–600 feet)	12
Ammonia reduction (78% reduction)	164 feet	1
Fecal coliform	129 feet (range 100–600 feet)	4
Nitrates in surface runoff	113 feet (range 33–279 feet)	5
Nitrates in shallow groundwater	168 feet (range 3–721 feet)	31
Nitrogen	87 feet (range 5–164 feet)	4
Pesticides	182 feet (range 164–200 feet)	2
Phosphorus	106 feet (range 53–200 feet)	6
Sediment	103 feet (range 30–300 feet)	19
Average Stream Buffer Width Needed to Filter Approximately 80% of Pollutants	**132 feet**	

Appendix I.

A Summary of 77 Scientific Studies Conducted on the Size of Stream Vegetated Buffers Needed to Protect Water Quality. The information in this appendix was taken from the text and tables of 5 review articles described above. The table summarizes (1) the purpose of the vegetated buffer that was tested in a scientific study (Vegetated Buffer Function); (2) the size (in meters and feet) of the vegetated buffer(s) tested; (3) the author of the scientific study who tested the buffer's function and size; and (4) the name of the review article where the scientific study was summarized. As much as possible, the studies in this table are listed from most protective to least protective. Note that information about maintaining water temperatures, recruiting large woody debris, and maintaining microclimate influences and instream habitat appear in Part II of this report series, *Scientific Recommendations on the Size of Stream Vegetated Buffer Needed to Protect Fish and Aquatic Habitat*.

FILTER POLLUTANTS—Nutrients* ***Depends on slope, soils, etc.**				
	Meters	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Nutrient removal—using the multi-species riparian buffer strip system described by the authors	20	66	Schultz et al 1995	Knutson and Naef 1997
Nutrient reduction—suggested distance to protect water quality	36	118	Young et al 1980	Knutson and Naef 1997; Wenger 1999
Nutrient reduction—buffers needed in forested riparian areas	30	100	Terrell and Perfetti 1989	Knutson and Naef 1997
Nutrient reduction—buffers needed in herbaceous or cropland riparian areas	183	600	Terrell and Perfetti 1989	Knutson and Naef 1997
Nutrient reduction—improve or protect water quality	≥10	≥33	Corley et al 1999	Fischer et al 2000
Nutrient reduction—improve or protect water quality from logging	≥30	≥100	Lynch et al 1985	Knutson and Naef 1997; Castelle et al 1994; Fischer et al 2000
Nutrient reduction—improve or protect water quality	≥18	≥60	Lynch et al 1985	Fischer et al 2000
Nutrient reduction—improve or protect water quality	≥15	≥50	Woodard and Rock 1995	Fischer et al 2000
Nutrient reduction—improve or protect water quality	≥25	≥82	Young et al 1980	Fischer et al 2000
Nutrient reduction—minimum buffer size recommended	10	33	Petersen et al 1992	Knutson and Naef 1997
Nutrient reduction	4	13	Doyle et al 1977	Knutson and Naef 1997; Castelle et al 1994; Fischer et al 2000
Nutrient reduction	16	52	Jacobs and Gilliam 1985	Knutson and Naef 1997
Nutrient reduction	30–43	100–141	Jones et al 1988	Knutson and Naef 1997

FILTER POLLUTANTS—Animal Waste* ***Depends on slope, soils, etc.**				
	Meters	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
78% ammonium reduction from surface water	50	164	Peterjohn and Correll 1984	Wenger 1999
71% ammonium reduction from surface water	21	70	Young et al 1980	Wenger 1999
20–50% ammonium reduction	6–18	20–50	Daniels and Gilliam 1996	Wenger 1999
Fecal coliform removed	30	100	Grismer 1981	Knutson and Naef 1997
Fecal coliform removed	30–43	100–141	Jones et al 1988	Knutson and Naef 1997
Fecal coliform removed	30	100	Lynch et al 1985	Knutson and Naef 1997
87% of fecal coliform removed	60	197	Karr and Schlosser 1977	Wenger 1999
34–74% of fecal coliform removed	9	30	Coyne et al 1995	Wenger 1999
Feedlot waste—distance needed to filter confined animal waste	183	600	Terrell and Perfetti 1989	Knutson and Naef 1997
80% of feedlot waste removed	91–262	300–860	Vanderholm and Dickey 1978	Castelle et al 1994
92% of suspended sediment removed from feedlot waste	24	80	Young et al 1980	Castelle et al 1994
33% of suspended sediment removed from feedlot waste	23	75	Schellinger and Clausen 1992	Castelle et al 1994

FILTER POLLUTANTS—Nitrogen in various forms* ***Depends on slope, soils, etc.**				
	Meters	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
NITRATES IN SURFACE RUNOFF				
Nearly 100%' nitrate reduction	20–30	66–100	Fennesy and Cronk 1997	Wenger 1999
Nitrates removed to meet drinking water standards	30	100	Johnson and Ryba 1992	Knutson and Naef 1997
99% nitrate reduction in forested buffer	10	33	Xu et al 1992	Castelle et al 1994
79% nitrate reduction in forest buffer	70–85	230–279	Peterjohn and Correll 1984	Wenger 1999; Mayer et al 2005
78% nitrate reduction in forest buffer	30	98	Lynch et al 1985	Mayer et al 2005
27–57% nitrate reduction in grassland buffer	5–9	15–30	Dillaha et al 1989	Mayer et al 2005
20–50% nitrate reduction in grassland buffer	8–16	26–53	Vought et al 1994	Wenger 1999
16–76% nitrate reduction in grassland buffer	26	85	Schwer and Clausen 1989	Mayer et al 2005

	Meters	Feet	Author of Original Scientific Study	Name of Review Article
NITRATES IN SURFACE RUNOFF (continued)				
12–74% nitrate reduction through wetland vegetation	20	66	Brüsch and Nilsson 1993	Mayer et al 2005
8% nitrate reduction in grassland buffer	27	89	Young et al 1980	Mayer et al 2005
Nitrates *increased* across buffer	21	70	Young et al 1980	Wenger 1999
Nitrates *increased* in grassland buffer	5–9	15–30	Dillaha et al 1988	Wenger 1999; Mayer et al 2005
NITRATES IN SHALLOW GROUNDWATER				
100% nitrate reduction	30	98	Pinay and Decamps 1988	Mayer et al 2005
100% nitrate reduction	30	98	Pinay et al 1993	Mayer et al 2005
100% nitrate reduction	40	131	Puckett et al. 2002	Mayer et al 2005
100% nitrate reduction	10–20	33–66	Vought et al 1994	Wenger 1999
99% nitrate reduction	50	164	Jacobs and Gilliam 1985	Mayer et al 2005
99% nitrate reduction	10	33	Cey et al 1999	Mayer et al 2005
98% nitrate reduction	100	328	Prach and Rauch 1992	Mayer et al 2005
97–99% nitrate reduction in grass-forest area	33–66	108–216	Vidon and Hill 2004	Mayer et al 2005
97% nitrate reduction	165	541	Hill et al. 2000	Mayer et al 2005
96% nitrate reduction in clay soils	1	3	Burns and Nguyen 2002	Mayer et al 2005
96% nitrate reduction	15	49	Hubbard and Sheridan 1989	Mayer et al 2005
95% nitrate reduction	200	656	Fustec et al 1991	Mayer et al 2005
95% nitrate reduction	60	197	Jordan et al 1993	Wenger 1999; Mayer et al 2005
94–98% nitrate reduction in forest area	204–220	669–721	Vidon and Hill 2004	Mayer et al 2005
94% nitrate reduction	50–60	160–200	Lowrance 1992	Wenger 1999; Mayer et al 2005
94% nitrate reduction	85	280	Peterjohn and Correll 1984	Mayer et al 2005
91% nitrate reduction	6	20	Borin and Bigon 2002	Mayer et al 2005
91% nitrate reduction	70	230	Hubbard and Lowrance 1997	Mayer et al 2005
90–99% nitrate reduction	50	164	Peterjohn and Correll [1] 1984	Wenger 1999
89% nitrate reduction	16	52	Haycock and Burt 1993	Mayer et al 2005

	Meters	Feet	Author of Original Scientific Study	Name of Review Article
NITRATES IN SHALLOW GROUNDWATER (continued)				
84–99% nitrate reduction	16–20	52–66	Haycock and Pinay 1993	Wenger 1999; Mayer et al 2005
84–98% nitrate reduction	25–50	82–164	Hefting and de Klein 1998	Mayer et al 2005
84–97% nitrate reduction	6–15	19–50	Simmons et al 1992	Mayer et al 2005
83% nitrate reduction	55	180	Lowrance et al 1984	Mayer et al 2005
83% nitrate reduction	20	66	Schultz et al 1995	Mayer et al 2005
82–99% nitrate reduction	10	33	Schoonover and Williard 2003	Mayer et al 2005
82–95% nitrates reduction	16–39	52–128	Osborne and Kovacic 1993	Wenger 1999; Mayer et al 2005
80–100% nitrate reduction	50–70	164–230	Martin et al 1999	Mayer et al 2005
80–81% nitrate reduction	20–28	66–92	Mander et al 1997	Wenger 1999
78% nitrate reduction	30	100	Hubbard 1997	Wenger 1999
78% nitrate reduction	38	125	Vellidis et al. 2003	Mayer et al 2005
64–100% nitrate reduction	100–200	328–656	Spruill 2004	Mayer et al 2005
60–99% nitrate reduction in grassland area	25–30	82–98	Vidon and Hill 2004	Mayer et al 2005
59–94% nitrate reduction[2]	31	102	Hanson et al 1994	Wenger 1999; Mayer et al 2005
58–96% nitrate reduction	10–50	33–164	Hefting et al 2003	Mayer et al 2005
52–76% nitrate reduction	5	16	Clausen et al. 2000	Mayer et al 2005
NITROGEN				
Nitrogen removed	30	100	Muscutt et al 1993	Wenger 1999
90–99% nitrogen reduction	5–9	15–30	Madison et al 1992	Castelle et al 1994
89% nitrogen reduction	19	62	Shisler et al 1987	Castelle et al 1994; Fischer et al 2000
86% nitrogen reduction in surface water	50	164	Peterjohn and Correll [1] 1984	Wenger 1999
67–74% nitrogen reduction	5–9	15–30	Dillaha et al 1988	Wenger 1999
67% nitrogen reduction	21	70	Young et al 1980	Wenger 1999
54–73% nitrogen reduction	5–9	15–30	Dillaha et al 1989	Castelle et al 1994; Wenger 1999
38% nitrogen reduction in grassland	91	299	Zirschky et al 1989	Mayer et al 2005
28–51% nitrogen reduction in grass/forest	8–15	25–50	Schmitt et al 1999	Mayer et al 2005
17–51% nitrogen reduction	5–9	15–30	Magette et al 1987	Wenger 1999

	Meters	Feet	Author of Original Scientific Study	Name of Review Article
NITROGEN (continued)				
Buffer zones less than 10 meters (33 feet) lack extensive experimental support	>10	>33	Hickley and Doran 2004	Mayer et al 2005
Nitrogen *increased* or reduced by 48%	5–9	15–30	Magette et al 1989	Wenger 1999; Mayer et al 2005
Nitrogen *increased* in groundwater	50	164	Peterjohn and Correll [1] 1984	Wenger 1999

FILTER POLLUTANTS—Pesticides and Heavy Metals* ***Depends on slope, soils, etc.**				
	Meters	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Pesticides—buffering distance for sediment with pesticides—ungrazed buffers	61	200	Terrell and Perfetti 1989	Knutson and Naef 1997
Pesticides—various types—almost 100% over 3 years	50	164	Lowrance et al 1997	Wenger 1999
Pesticides—various types—8–100% reduction	20	66	Arora et al 1996	Wenger 1999
Pesticides—various types—10–40% reduction	12–60	40–60	Hatfield et al 1995	Wenger 1999
Lead removal	61	200	Horner and Mar 1982	Castelle et al 1994

FILTER POLLUTANTS—Phosphorus* ***Depends on slope, soils, etc.**				
	Meters	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
100% phosphorus reduction	61	200	Horner and Mar 1982	Castelle et al 1994
80% phosphorus reduction	19	62	Shisler et al 1987	Castelle et al 1994; Fischer et al 2000
73–84% phosphorus reduction—in surface water	50	164	Peterjohn and Correll 1984	Wenger 1999
67–81% phosphorus reduction in short-term study	20–28	66–92	Mander et al 1997	Wenger 1999
83% phosphorus reduction in short-term study	21–27	70–90	Young et al 1980	Wenger 1999
66–95% phosphorus reduction in surface water in short-term study	8–16	26–53	Vought et al 1994	Wenger 1999
61–79% phosphorus reduction in short-term study	5–9	15–30	Dillaha et al 1989	Castelle et al 1994; Wenger 1999
58–72% phosphorus reduction in short-term study	5–9	15–30	Dillaha et al 1988	Wenger 1999
41–53% phosphorus reduction in short-term study	5–9	15–30	Magette et al 1987	Wenger 1999
18–46% phosphorus reduction in short-term study	5–9	15–30	Magette et al 1989	Wenger 1999

FILTER POLLUTANTS—Sediments* ***Depends on slope, soils, etc.**				
	Meters	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Sediment removal—adequate buffer for cropland, animal waste across ungrazed buffer, and for pesticides	61	200	Terrell and Perfetti 1989	Knutson and Naef 1997
Sediment removal	30	100	Moring et al 1982	Knutson and Naef 1997
Sediment removal—to prevent impacts in logged forest	30	100	Davies and Nelson 1994	Wenger 1999
Sediment removal—based on multi-year studies	30	100	Cooper et al 1988	Wenger 1999
Sediment removal—minimum needed	30	100	Erman et al 1977	Wenger 1999
Effective sediment removal—most effective width of vegetated buffers	25	82	Desbonnet et al 1994	Wenger 1999
Effective sediment removal—adequate buffer for logging practices on steep slopes—buffer measured from edge of floodplain	61	200	Broderson 1973	Knutson and Naef 1997; Castelle et al 1994
Effective sediment removal—buffer strip width to control non-channelized sediment flow	60–91	200–300	Belt et al 1992	Knutson and Naef 1997
99% sediment reduction in short-term study (1 rainfall)	9	30	Coyne et al 1995	Wenger 1999
90–94% sediment reduction in short-term study	19–60	62–197	Peterjohn and Correll 1984	Wenger 1999
90% sediment reduction at 2% grade	30	100	Johnson and Ryba 1992	Knutson and Naef 1997
85% sediment reduction	9	30	Ghaffarzadeh et al 1992	Castelle et al 1994
80% sediment reduction	61	200	Horner and Mar 1982	Castelle et al 1994
76–95% sediment removal in short-term study	5–9	15–30	Dillaha et al 1988	Wenger 1999
75–80% sediment reduction from logging activity	30	100	Lynch et al 1985	Knutson and Naef 1997; Castelle et al 1994; Fischer et al 2000
75–80% sediment reduction from stormwater in logged areas; more effective where runoff is in sheets; less effective where surface flows are channelized	30	100	Johnson and Ryba 1992	Knutson and Naef 1997
75% sediment reduction	30–38	100–125	Karr and Schlosser 1977	Knutson and Naef 1997
70–84% sediment reduction	5–9	15–30	Dillaha et al 1989	Castelle et al 1994; Wenger 1999
66–93% sediment reduction in short-term study	21–27	70–90	Young et al 1980	Castelle et al 1994; Wenger 1999; Fischer et al 2000
66–82% sediment reduction in short-term study	5–9	15–30	Magette et al 1989	Wenger 1999
50% sediment reduction—based on muti-year studies	100	328	Lowrance et al 1988	Wenger 1999
50% sediment reduction	88	289	Gilliam and Skaggs 1988	Knutson and Naef 1997

1 NOTE: Wenger (1999) refers to two articles written by Peterjohn and Correll: one from 1984 and one from 1985. It appears that the article he cited was Peterjohn and Correll 1984.

2 NOTE: Wenger (1999) reported a 94% reduction in nitrates for this study while Mayer et al (2005) reported a 59% reduction. Both figures are presented.

Appendix II

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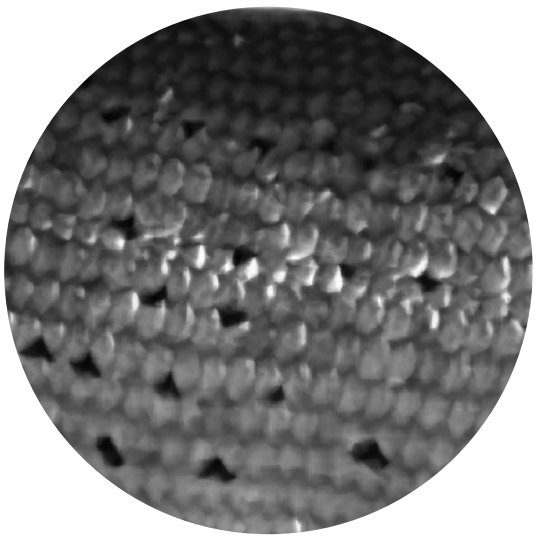
Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Fish and Aquatic Habitat

PART Two of a Series entitled:
The Need for Stream Vegetated Buffers:
What Does the Science Say?



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This report is available at mtaudubon.org

Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Fish and Aquatic Habitat

Introduction

All freshwater fish depend primarily on two things: 1) an adequate, clean water supply, and 2) a healthy system of riparian vegetation along our streams, lakes, and wetlands. These two items work in tandem to provide the necessary areas for breeding, feeding, resting, and avoiding predators during the different phases of a fish's lifecycle. One of the most effective tools available to local governments interested in minimizing the loss and degradation of fish habitat along streams is to set back structures and protect streamside buffers with native vegetation (hereafter referred to as "building setbacks with vegetated buffers"). In order to use this tool, however, decision makers and citizens alike must understand the science behind different buffer widths.

This second report, in a series, summarizes the scientific recommendations underlying the vegetated buffer size needed to protect fish and aquatic habitat. Two other reports were developed in this series on other key elements of stream protection, water quality and wildlife:

- *Part I: Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Water Quality*; and
- *Part III: Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Wildlife and Wildlife Habitat.*

Each of these reports is designed to explain the science behind one of the many functions provided by vegetated buffers found along streams. Other topics for this series are currently being considered because decision makers establishing building setbacks with vegetated buffers should also consider floodplains and seasonal water levels, stream migration corridors, density of development adjacent to the riparian corridor, and other factors.

For more information on how building setbacks relate to vegetated buffers, see page 3.

Building Setbacks and Vegetated Buffers

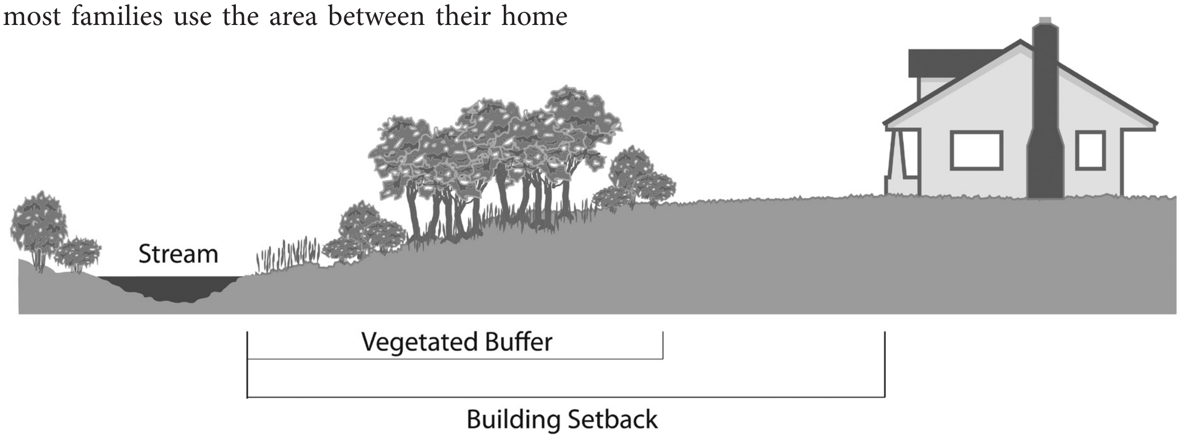
In order to understand setbacks and buffers, it is important to understand the following concepts:

Building setbacks or "no build areas" are the distance from a stream's ordinary high water mark to the area where new structures and other developments (such as highly polluting land uses—including roads, parking lots, and waste sites) are allowed.

Vegetated Buffers are not an additional area, but rather the portion of the building setback that is designated to remain undisturbed. These buffers are areas where all native vegetation, rocks, soil, and topography are maintained in their natural state, or enhanced by additional planting of native plants. Lawns should not be considered part of the vegetated buffer. With their shallow roots, lawns are not particularly effective at absorbing and retaining water, especially during heavy rains. Consequently, they do not significantly filter out water pollutants. They can also be a major source of fertilizers and pesticides—substances that should be prevented from entering our streams and rivers.

How much space should be placed between a building and a vegetated buffer? The building setback should be wide enough to prevent degradation of the vegetated buffer. As an example, most families use the area between their home and the vegetated buffer for lawns, play areas, swing sets, picnic tables, vegetable gardens, landscaping, etc. As a result, the building setback should extend at least 25–50 feet beyond the vegetated buffer (Wenger 1999). A smaller distance between a building and a vegetated buffer, such as 10 feet, will most likely guarantee degradation of the vegetated buffer. A greater distance between structures and a vegetated buffer is recommended if the:

- River has a history of meandering; the setbacks should ensure that people and homes will not unwittingly be placed too close to the river's edge, in harm's way.
- Vegetated buffer is narrower than scientific studies recommend; a deeper building setback can help protect water quality, fisheries, and aquatic habitat.
- Land is sloped and runoff is directed toward the stream (the steeper the slope, the wider a buffer or setback should be).
- Land use is intensive (subdivisions, crops, construction, development).
- Soils are erodible.
- Land drains a large area.
- Aesthetic or economic values need to be preserved.
- Wildlife habitat needs to be protected.
- Landowners desire more privacy.



A Definition of Riparian Areas

This term means "related to, living on, or located on" the bank of a stream or lake. Riparian areas occur along the shorelines of streams, rivers, lakes, and reservoirs. Some are narrow bands stretching along mountain streams, others stretch thousands of feet beyond the water's edge across broad floodplains. Plants associated with riparian areas include cottonwoods, willows, dogwood, alder, sedges, forbs, cattails, and more.

Vegetated Buffers, Fish & Aquatic Habitat

There is a growing concern in Montana over the status of our native fish communities. Keeping an adequate vegetated buffer along a stream is the most important thing that individual landowners can do to improve or maintain fish habitat—both for the stream passing thorough a landowner's property, as well as for the river downstream. In Montana, we have 85 species of fish that depend on healthy streams, including 51 species of native fish and 32 non-native (introduced) fish. Two additional species are possibly native. Twenty-six of these species are considered game fish, important to fishing and the economy (Holton and Johnson, 2003).

In order to understand the habitat requirements of fish, two basic principles should be understood. First, a stream with a healthy invertebrate population (e.g. aquatic insects, crustaceans, snails, and worms) usually indicates that the fish habitat is also healthy. Aquatic invertebrates are the major food source for many, if not most, freshwater fish. Even predacious fish feed heavily on invertebrates when they are juveniles. As a result, scientific studies on fish frequently focus on the health of a stream's invertebrate populations.

A second principle worth emphasizing is that natural stream processes are critical for most fish species because fish have evolved with natural processes—and the habitat requirements of fish are diverse. As an example, some fish prefer small streams (e.g. creek chub, brassy minnow, several species of sculpin, many spawning fish), others are primarily found in large rivers or lakes (e.g. burbot, gar, paddlefish, sturgeon, walleye); some require clear, cold water (e.g. trout, grayling, whitefish, mountain suckers), while others need turbid, warmer water (e.g. channel catfish, some chub, goldeye, sauger, sunfish); some species prefer pools and backwater areas (e.g. river carpsucker, largemouth bass), while others prefer strong currents (e.g. pallid and shovelnose sturgeon, stonecat); some like dense aquatic vegetation (e.g. carp, peamouth, pike, shiners, stickleback), while others need clear water and overhanging vegetation (many trout); and some fish prefer a gravel stream bottom (e.g. rock and smallmouth bass, many spawning fish), while others prefer a sandy or muddy bottom (e.g. largemouth bass, sand shiner, black bullhead) (Holton and Johnson, 2003). Additionally, fish can use different parts of the aquatic environment during different parts of their lifecycle. As an example, bull trout use larger streams or lakes during much of the year, but use small, clean gravel-bottomed streams to spawn. Because different fish have different habitat requirements, maintaining natural

Artwork of the burbot by Joe Tomelleri, courtesy Montana Fish, Wildlife & Parks.

stream processes is the simplest way to protect Montana's diverse fish populations.

Specific ways that streamside buildings and their associated development (roads, parking lots, construction sites, etc.) can impact fish and aquatic habitat are described below:

Riparian Vegetation and Woody Debris

Fish and aquatic insects need clean water. Riparian vegetation plays a critical role at keeping sediments and other pollutants out of our streams and rivers (see *Sedimentation* below). It also is the main source of leaves, twigs, and other organic material that provides a large proportion of the food and breeding grounds for invertebrates that, in turn, feed fish and other wildlife.

Large woody debris (LWD), which is generally defined as pieces of wood at least 20 inches (51 cm) in diameter, is important to both Montana's cold and warm water fisheries. When trees, root systems, branches, and other LWD fall into streams, they create critical fish habitat by developing: scour holes, rifles, and areas for spawning gravels to accumulate; pool habitats that provide critical refuges when summer temperatures get high; and small dams that keep natural organic litter and food from washing downstream, which helps fish as well as the invertebrates they eat. Trees also provide underwater resting areas and cover from predators in roots, submerged logs, and other debris. Scientists consider LWD to be one of the most important factors in determining critical habitat for trout and salmon (salmonids) (Knutson and Naef 1997).

Construction of homes and their associated developments along streams and rivers often results in removal of riparian vegetation and woody debris because of the human tendency to "manage their property" and "tidy up the yard." Removing trees—including dead tree snags—in riparian areas or cleaning trees from the stream can cause stream channels to become simpler and less stable. Simpler stream channels mean fewer, shallower, and less-complex pool habitats; more distance between low-velocity refuges for fish during high flows; and fewer places for fish to hide or escape from predators. Additionally, less large woody debris in a stream reduces the retention and sorting of spawning gravels, as well as the amount of leaf litter and other organic material available for invertebrates.

> Local governments interested in determining the fish species using streams within their jurisdiction should contact their local office of Montana Fish, Wildlife & Parks and the Montana Natural Heritage Program located in Helena (406–444–5354 or http://nhp.nris.mt.gov/).

Stream Temperatures

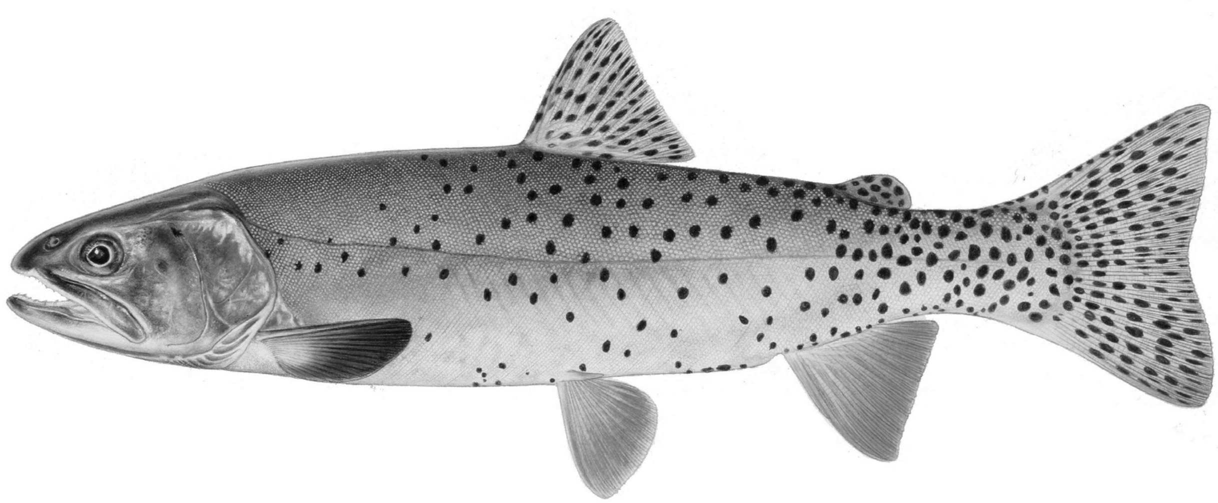
Fish are 'cold-blooded' animals. Consequently, their body temperature is about the same as the water temperature in which they live (i.e. if the water is hot, the fish are hot)—and the water temperature directly influences their rate of development, metabolism, and growth. Water temperatures also influence the amount of dissolved oxygen in water, with less oxygen found in warmer temperatures. Both of these factors influence the range and distribution of fish species in Montana. As an example, we have cold water fish, primarily located in the western part of the state, and warm water fish, primarily located in eastern Montana. Cold water fish include trout, salmon, and whitefish; they are adapted to living in water temperatures

lower than 65° F (<18° C). Warm water fish include largemouth and smallmouth bass, northern pike, tiger muskie, channel catfish, sauger, and pallid sturgeon; these fish must have summer water temperatures of 75 ° F or higher (>24° C). Because fish are so sensitive to temperature—even minor shifts in temperature can cause changes in the fish community—having shade over the surface of streams is a critical part of fish habitat. By shading sections of a stream channel, trees and shrubs, such as cottonwoods, birch, alder, pine, and willow, help control and moderate water temperature, keeping streams cooler in the summer and warmer in the winter. Streamside vegetation also protects streams from wind and increases the local humidity, both important factors for some adult stages of aquatic insects.

Removal of vegetation that provides shade can result in summer temperatures that can be stressful or lethal to invertebrates and fish—for both cold and warm water fisheries.

The Role of Small Streams

Small, tributary streams need and deserve at least as much protection as larger rivers because they: contribute steady amounts of clean, cooler water to mainstem rivers; filter sediments and pollutants; play a key role in the retention and absorption of flood and storm water in a watershed; are an important water source, especially during low flow periods of the year; are a major source of woody debris and other organic matter necessary for aquatic organisms; and provide critical spawning sites for many fish species. In terms of temperature, even small streams that do not hold fish can benefit from shade, which keeps water cooler for habitat downstream. Additionally, small streams that are shaded provide the greatest temperature reduction per unit length—directly benefiting Montana's mainstem rivers. These streams are so critical for Montana's fisheries that an increase in the temperature and/or sedimentation of tributary streams can directly decrease the useable habitat for fish, as well as reduce their reproductive success.



Artwork of the Yellowstone cutthroat by Joe Tomelleri, courtesy Montana Fish, Wildlife & Parks.

This home was built out of the floodplain—but on an erosive bank overlooking the Shields River. In areas where streams are known to meander, building setbacks and vegetated buffers should incorporate non-floodplain areas overlooking the stream—because as valley stream channels naturally meander, these homes can become vulnerable to falling into the water.

Because of their size, small tributaries are very vulnerable to impacts from housing and other development: they are shallower, so removing trees and other shade-producing vegetation can result in harmful increases in temperature and increased evaporation rates; and they have less water, so it is easier for debilitating or toxic concentrations of pollutants to impact aquatic organisms in these streams. Additionally, many small tributaries are often dependent upon groundwater to maintain late summer stream flows. If a housing development reduces or eliminates their access to this groundwater, these streams can partially or entirely dry up—a condition that is obviously stressful or lethal to fish and other stream organisms.

Bank Stabilization

As described above, the long-term health of streams, fish, and aquatic habitat requires maintaining natural stream processes—which includes natural erosion processes. In a healthy valley stream or river, banks erode naturally and the material is deposited elsewhere, which in turn builds banks and their associated floodplain. As a result of this natural process, the location of the stream channel changes over time. If given space, meandering streams create a pattern where outside bends of the stream are dominated by cut banks (caused by natural erosion), and inside bends are dominated by sand or gravel bars (where sediment is deposited).

If homes or other developments are built too close to a meandering stream or on a bluff overlooking a river, landowners will eventually request that bank stabilization structures—riprap, weirs, barbs, and other structures—be built to protect their home from eventually falling into the water. As more bank stabilization structures are built, both short-term and long-term consequences arise. In the short-term, stabilization measures tend to physically secure one local stretch of riverbank or divert flows away from one bank to another. This can trigger increases in river flow velocities, exacerbate downstream bank erosion, and lead to further instabilities downstream. In other words, preventing natural erosion at one location can significantly increase erosion downstream of the project. Therefore the "problem" is neither controlled nor solved, but merely relocated from one spot to another, negatively impacting downstream landowners. Increased downstream erosion often causes affected landowners to put in structures to protect their property—and the cycle repeats itself over and over again. Scientific studies show that structurally diverse streams, unmodified by human activity, are critical to sustaining fish populations (e.g. Schmetterling et al 2001). In the long-term, bank stabilization structures negatively impact fish habitat by simplifying the structure of the stream, resulting in a loss of species and fish numbers. The simplest way to eliminate this problem is to not allow homes and other associated development to be built in the floodplain—and to establish setbacks in areas located above the floodplain where streams will likely meander.

Sedimentation

In addition to being sensitive to water pollutants, fish can be extremely intolerant of sediment in the stream. Sediments come from a variety of sources, including natural and human-driven stream bank erosion, agricultural fields, exposed earth at construction sites and on dirt roads, and other activities that remove vegetation and expose soil. Scientific studies show that, during heavy rainstorms, land covered with native riparian vegetation can absorb 95% of the precipitation, depositing only 5% of the relatively silt-free water into nearby streams (Knutson and Naef 1997). Although many Montana fish are somewhat tolerant of sediment, many of our trout species—including our native bull trout and cutthroat trout—tend to be very sensitive to siltation. As an example, trout require and seek out clean (silt-free) gravel to lay their eggs. Fine sediment suspended in water will suffocate eggs and interfere with the feeding of juvenile trout, reducing their growth rates. And trout are not the only fish affected by too much sedimentation: several of Montana's warm water fish need clean gravels to spawn, including the long-nosed dace, stonecat, and goldeye. Too much suspended sediment can also cause irritation of gill tissues and force fish to avoid a stream or section of stream altogether. The bottom line is that sediment deposited on stream beds reduces habitat for fish and for the invertebrates that many fish consume—and high levels of sediment can kill aquatic insects and fish.

Removing riparian vegetation, including manicuring the landscape, reduces the ability of natural vegetation to filter out sediments and other pollutants. As stated earlier, keeping an adequate vegetated buffer along a stream is the single most important thing individual landowners can do to improve or maintain fish habitat. For more information on the role that vegetated buffers play in protecting water quality, see the water quality report in this series (Ellis 2008).

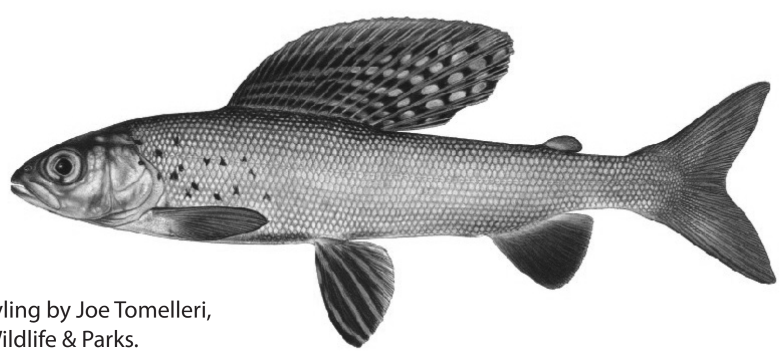
About This Report—Methods Used

This report summarizes the recommendations of more than 34 scientific studies that tested how various stream vegetated buffers protected fish and aquatic habitat (see *Appendix I*). These scientific studies were reviewed by the authors of 3 review publications. One additional source was included because it contains on-the-ground management recommendations for fisheries in Montana. Please note that the information in this report was taken from the text and tables of these 4 publications—and that the original studies were not reviewed. The 3 review publications are:

Castelle, A.J., A. W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirements—a review. J. Environ. Qual. 23: 878–882.

Knutson, K. L. and V. L. Naef. 1997. Management recommendations for Washington's priority habitats: riparian. Wash. Dept. Fish and Wildlife, Olympia, WA. 181 pp.

Wenger, S. J. 1999. A review of the scientific literature on riparian buffer width, extent and



Artwork of the Arctic grayling by Joe Tomelleri, courtesy Montana Fish, Wildlife & Parks.

vegetation. Athens: Institute of Ecology Office for Public Service and Outreach, University of Georgia. 59 pp.

Appendix II contains the original references cited in these 3 review publications, allowing individuals using Appendix I to see the full title of all original references, as well as have sufficient information to access all references, if necessary.

Information from one additional publication is included in this report:

INFISH. 1995a. Inland Native Fish Strategy Environmental Assessment, Decision Notice and Finding of No Significant Impact for the Inland Native Fish Strategy, U.S. Forest Service, Intermountain, Northern and Pacific Northwest Regions, Coeur d'Alene, Idaho. 18 pp.

The Inland Native Fish Strategy (INFISH 1995a) was included in this report because it was specifically developed to protect native fish communities and their habitats on U.S. Forest Service and U.S. Bureau of Land Management (BLM) land in the inland West. In Montana the INFISH standards are currently used on BLM land in western Montana, as well as on the Bitterroot, Deerlodge, Flathead, Helena, Kootenai, and Lolo National Forests, which includes approximately the western third of Montana. The buffers established in INFISH are based on empirical science on the size of the stream buffer needed to ensure sediment is intercepted, shade trees are retained for the long-term, and large enough trees are preserved to supply woody debris over the long-term. More than 70 scientific references were used to develop these standards. Unlike traditional scientific papers, the specific studies that led to a specific buffer width are not referenced in the body of the text. Instead, the references all appear in Appendix C of the INFISH Environmental Assessment (INFISH 1995b). As a result, individule scientific studies used to establish the INFISH standards do not appear in Appendix I. Although the 1995 INFISH guidelines are called "interim," they are still in use today—either as part of updated National Forest management plans or as the on-the-ground policy used by National Forests with older management plans.

Summary of Scientific Recommendations

With growing concerns over the health of native fish communities, the future of Montana's fish populations depend on the protection of vegetated buffers along our streams. Consequently:

In order to maintain fish and aquatic habitat, scientific studies recommend that a:

- ***100-foot (30-meter) riparian vegetated buffer should be maintained at a minimum;***
- ***150-foot (46-meter) vegetated buffers should be maintained in forested areas—including areas in Montana with cottonwood gallery forests—so that large woody debris recruitment is sustained; and***
- ***Multi-tiered system should be considered in areas occupied by native bull trout and cutthroat trout, with 300-foot buffers recommended on fish-bearing streams (3 tree lengths); 150-foot buffers on non-fish-bearing streams and reservoirs; and 100-foot buffers on seasonally active (intermittent or ephemeral) streams (1 tree length).***

These recommendations are drawn from the conclusions of 4 publications that reviewed more than 34 separate scientific studies on fish, aquatic habitat, and stream vegetated buffers. Specific conclusions and recommendations by the 4 review publications are summarized or quoted in Table I.

Table I. A summary of the specific conclusions and recommendations of four publications on the size of vegetative buffer needed to protect fish and aquatic habitat.	
Castelle et al 1994	100-foot (30-meter) buffer was recommended.
INFISH 1995	INFISH recommends a multi-tiered system to protect fisheries in the western third of Montana:
	Fish-bearing Streams: vegetated buffers should "consist of the stream and the area on either side of the stream extending from the edges of the active stream channel to the top of the inner gorge, or to the outer edges of the 100-year floodplain, or to the outer edges of riparian vegetation, or to a distance equal to the height of two site-potential trees, or **300 feet slope distance (600 feet, including both sides of the stream channel)**, whichever is greatest."
	Permanently Flowing, Non-fish-bearing Streams: vegetated buffers should "consist of the stream and the area on either side of the stream extending from the edges of the active stream channel to the top of the inner gorge, or to the outer edges of the 100-year floodplain, or to the outer edges of riparian vegetation, or to a distance equal to the height of one site-potential tree, or **150 feet slope distance (300 feet, including both sides of the stream channel)**, whichever is greatest."
	Ponds, Lakes, Reservoirs, and Wetlands Greater than 1 Acre: vegetated buffers should "consist of the body of water or wetland and the area to the outer edges of the riparian vegetation, or to the extent of the seasonally saturated soil, or to the extent of moderately and highly unstable areas, or to a distance equal to the height of one site-potential trees, or **150 feet slope distance from the edge of the maximum pool elevation of constructed ponds and reservoirs or from the edge of the wetland, pond, or lake**, whichever is greatest."
	Seasonally Flowing or Intermittent Streams, Wetlands Less than 1 Acre in Size, Landslides, and Landslide-prone Areas: vegetated buffers should consist of the "intermittent stream channel or wetland and the outer edges of the riparian vegetation" and 1. For priority watersheds, a "distance equal to the height of one site-potential tree, or **100 feet slope distance**, whichever is greatest," or 2. For watersheds not identified as a priority, a "distance equal to the height of one-half site-potential tree, or **50 feet slope distance**, whichever is greatest."
Knutson and Naef 1997	The following average buffer widths were derived from scientific studies testing various components of fish habitat: • Control Erosion: 34-meter (112-foot) buffers; • Maintain Large Woody Debris: 45-meter (150-foot) buffers; • Control Temperature: 27-meter (90-foot) buffers; and • Filter Sediments: 42-meter (138-foot) buffers. However, to maintain fish populations and fish habitat, at least a 45-meter (150-foot) vegetated buffer is recommended because without adequate large woody debris recruitment, a critical habitat component is missing from the aquatic ecosystem.
Wenger 1999	To protect aquatic resources, a "30 m (98 ft) buffer" was recommended.
	"To provide maximum protection from floods and maximum storage of flood waters, a buffer should include the entire floodplain. Short of this, the buffer should be as wide as possible and include all adjacent wetlands."
	"Native vegetation should be preserved whenever possible."

In order to better understand the conclusions found above, Table II summarizes the scientific buffer width recommendations for various habitat components important to fish. It should be noted that because large woody debris recruitment is so important to fisheries, maintaining a 150-foot (45-meter) buffer is recommended in forested areas throughout the state, including areas with cottonwood gallery forests. Additionally, in order to maintain natural stream processes, all vegetative buffers should include the 100-year floodplain whenever possible.

Appendix I contains study-specific information for erosion control, large woody debris, temperature control, invertebrates, and specific fish species. It should be noted that many of the studies found in Appendix I underwent extensive peer review before they were published in a professional journal or report of a scientific government agency. It would be very costly to duplicate these studies on a case-by-case basis; hence the recommendations given here are intended to be protective in most situations, based on the findings of a wide range of studies. If localized information on area conditions is available (vegetation maps, floodplain maps, etc.), this information can also be used to ensure that buffers more accurately fit local conditions.

Table II. Summary of stream vegetated buffer widths recommended to protect fish and aquatic habitat. This table was compiled using information in the 4 publications reviewed in this report, from the detailed conclusions from scientific studies reported in Appendix I below. This table gives the average vegetative buffer width recommended for fish and aquatic habitats using all studies found in Appendix I. Where studies reported a range of values, the median of that range was used to calculate the average (mean) buffer width. Because each habitat component plays a critical role in the health of aquatic habitat, the overall recommendation to maintain fish and aquatic habitat is the largest distance needed by any one habitat component: approximately 150 feet is needed to maintain large woody debris recruitment and scientific studies recommend that vegetative buffers should include the 100-year floodplain whenever possible.

Purpose of Vegetated Buffer	Average Stream Buffer Width	Number of Studies Used in Calculating Desired Buffer Width
Erosion control	100-year floodplain, but at least 100 feet	Review article conclusion (Wenger 1999)
Flood control, includes channel migration ability	100-year floodplain	Review article conclusion (Castelle et al 1994)
Road Construction	150 feet	1
Large Woody Debris	155 feet	14
Water Temperature Control	77 feet	15
Fish Habitat and Invertebrates	110 feet	20
Stream Buffer Width Needed for Fish and Aquatic Habitat	155 feet or 100-year floodplain, whichever is greatest	

Appendix I.

Summary of more than 34 Scientific Studies Conducted on the Size of Stream Vegetated Buffers Needed to Protect Fish and Aquatic Habitat. The information in this table was taken from the text and tables of the 4 publications described above. This table summarizes (1) the purpose of the buffer that was tested in a scientific study (Vegetated Buffer Function); (2) the size (in meters and feet) of the vegetated buffer tested; (3) the author of the scientific study who tested the buffer's function and size; and (4) the name of the publication where the scientific study was summarized. As much as possible, the studies in this table are listed from most protective to least protective. Note that information about removal of sediment and other pollutants appears in Part I of this report series, *Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Water Quality*.

GENERAL STREAM PROTECTION AND BANK STABILITY* *Depends on slope, soils, etc.				
Vegetated Buffer Function	**Distance from stream in meters**	**Distance from stream in feet**	**Author of Original Scientific Study**	**Name of Review Article**
Flood Control—Flood water elevation reduced 50% in forested vegetation	100-year floodplain	100-year floodplain	Bertulli 1981	Castelle et al 1994
Sediment control from roads—minimize locations of roads within 150 feet of streams (for sediment control)	46	150		INFISH 1995a
Bank erosion control—must allow channel migration	100-year floodplain	100-year floodplain		Wenger 1999
Bank erosion control—to prevent unnatural erosion	30	100	Raleigh et al 1986	Knutson and Naef 1997
Bank erosion control—1 effective tree height around channel migration zones; some tree harvest allowed between 20–100 feet	30	100		INFISH 1995a
Bank erosion control—in areas prone to high mass wasting (where large masses of rock or earth are likely to move down slope)	38	125	Cederholm 1994	Knutson and Naef 1997
General Stream Protection—Provides minimal maintenance of most stream functions	15–30	50–98	Johnson and Ryba 1992	Knutson and Naef 1997

LARGE WOODY DEBRIS RECRUITMENT				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Long-term large woody debris recruitment—minimum buffer to provide adequate large woody debris in streams	100	328	K. Koski, pers. comm.	Knutson and Naef 1997

LARGE WOODY DEBRIS RECRUITMENT (continued)				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Long-term large woody debris recruitment—3 tree lengths needed long-term in forested areas for stability (e.g. to minimize windthrow, where trees are uprooted by wind)	90	300	Collier et al 1995	Wenger 1999
Long-term large woody debris recruitment—1 effective tree height around all channel migration zones needed	30 meters from channel migration zone	100 feet from channel migration zone		INFISH 1995a
Large woody debris in stream maintained	55	180	Thomas et al 1993	Knutson and Naef 1997
Large woody debris in stream maintained	55	180	U.S. For. Serv. et al 1993	Knutson and Naef 1997
Large woody debris in stream maintained	46	150	McDade et al 1990	Knutson and Naef 1997
Large woody debris in stream maintained	46	150	Robison and Beschta 1990	Knutson and Naef 1997
100% of large woody debris for stream recruited within this distance	50	165	Van Sickle and Gregory 1990	Knutson and Naef 1997
99% of large woody debris for stream recruited within this distance	30	100	Murphy and Koski 1989	Knutson and Naef 1997
80% of large woody debris for stream recruited within this distance in coniferous riparian forest	30	100	Van Sickle and Gregory 1990	Knutson and Naef 1997
80% of large woody debris recruited within this distance in multiple canopy forest area	15	50	Van Sickle and Gregory 1990	Knutson and Naef 1997
Large woody debris contributed to stream structure within this distance	31	103	Bottom et al 1983	Knutson and Naef 1997
Tree falling distance—maximum distance of tree-fall (source of coarse woody debris)	45	148	Harmon et al 1986	Knutson and Naef 1997
Tree falling distance—median distance of tree-fall (source of coarse woody debris)	15	50	Harmon et al 1986	Knutson and Naef 1997
Short-term large woody debris recruitment—one tree height necessary for recruitment	30	100	Collier et al 1995	Wenger 1999
Winter fish habitat—salmonid survival in winter depended upon the amount of woody debris in streams; buffers this wide provided sufficient woody debris recruitment	15–130	49–427	Murphy et al 1986	Wenger 1999

WATER TEMPERATURE CONTROL				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Amount of stream surface shaded—provided 60–80% shading of streams at minimum flow	46	151	Steinblums et al 1984	Knutson and Naef 1997
Amount of stream surface shaded—provided 50–100% shading of streams	30–43	100–141	Jones et al 1988	Knutson and Naef 1997
Amount of stream surface shaded—same level of shading provided as that of an old growth forest	30	100	Beschta et al 1987	Knutson and Naef 1997; Castelle et al 1994
Amount of stream surface shaded—provided 50–100% shading of streams	18–38	60–125	U.S. Forest Service et al 1993	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	18	59	Moring 1975	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	15–30	49–100	Hewlett and Fortson 1982	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	12	39	Corbett and Lynch 1985	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	11–38	35–120	Johnson and Ryba 1992	Knutson and Naef 1997
Amount of stream surface shaded—provided 60–80% shading of streams	11–37	35–125	Brazier and Brown 1973	Knutson and Naef 1997
Water temperature maintained within 1 ºC (~ 0.6 ºF) of former average temperature	30	100	Lynch et al 1985	Knutson and Naef 1997; Castelle et al 1994
Water temperature maintained within 1º of baseline	30	100	Johnson and Ryba 1992	Knutson and Naef 1997
Water temperature important upstream—to maintain temperatures for fish, 80% of banks for 2.5 km (1.5 miles) upstream had to have at least a 10 meter buffer	10	33	Barton et al 1985	Wenger 1999
Canopy maintained	23	75		INFISH 1995a
Small stream water temperature sufficiently maintained on small streams by forested buffer of this size.	24	73	Brazier and Brown 1973	Castelle et al 1994
Small streams water temperature adequately controlled with buffers of this size	15	50	Broderson 1973	Castelle et al 1994
Small streams water temperature effectively maintained, especially on smaller streams	10–30	33–100	Osborne and Kovacic 1993	Wenger 1999

FISH AND AQUATIC HABITAT				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Fish-bearing streams—greatest distance: 300 feet, or edge of 100-year floodplain, or distance equal to 2 site-potential trees, or outer edge of riparian vegetation	91	300		INFISH 1995a
Ponds, lakes, reservoirs, and wet-lands—greatest distance: 150 feet, or edge of 100-year floodplain, or distance equal to 1 site-potential tree, or outer edge of riparian vegetation	46	150		INFISH 1995a
Non-fish-bearing streams—greatest distance: 150 feet, or edge of 100-year floodplain, or distance equal to 1 site-potential tree, or outer edge of riparian vegetation	46	150		INFISH 1995a
Seasonally flowing or intermittent streams—greatest distance: 100 feet, or distance equal to 1 site-potential tree, or outer edge of riparian vegetation	30	100		INFISH 1995a
Invertebrates—macroinvertebrate density begins to increase with buffer this size	30	100	Newbold et al 1980	Knutson and Naef 1997
Invertebrates—macroinvertebrate diversity—Shannon index of macroin-vertebrate diversity same as control with buffer of this size	30	100	Gregory et al 1987	Knutson and Naef 1997
Invertebrates—maintain riparian inver-tebrate populations	30	100	Roby et al 1977	Knutson and Naef 1997
Invertebrates—minimum width of ripar-ian buffer to avoid affecting food supply of benthic invertebrates	30	100	Erman et al 1977	Knutson and Naef 1997; Castelle et al 1994
Invertebrates—protect aquatic insect communities from sedimentation	30	100	Erman et al 1977	Knutson and Naef 1997
Aquatic habitat—maintain leaf litter in medium to large streams	30	100		INFISH 1995a
Aquatic habitat—maintain leaf litter in small streams	15	50		INFISH 1995a
Fish habitat—maintain fish habitat for brook trout	30	100	Raleigh 1982	Knutson and Naef 1997
Fish habitat—maintain fish habitat for chinook salmon	30	100	Raleigh et al 1986	Knutson and Naef 1997
Fish habitat—maintain fish habitat for cutthroat trout	30	100	Hickman and Raleigh 1982	Knutson and Naef 1997
Fish habitat—maintain fish habitat for rainbow trout	30	100	Raleigh et al 1984	Knutson and Naef 1997
Fish habitat—recommended buffer to control erosion of undercut banks for cutthroat, rainbow, and brown trout; and chinook salmon	30	100	Raleigh et al 1986	Knutson and Naef 1997

FISH AND AQUATIC HABITAT (continued)				
Vegetated Buffer Function	**Meters**	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Fish spawning—buffer needed by salmonid eggs for normal development	30	100	Moring 1982	Castelle et al 1994
Instream habitat—minimal maintenance of most functions	15–30	40–100	Johnson and Ryba 1992	Knutson and Naef 1997

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Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Wildlife and Wildlife Habitat

PART Three of a Series entitled:
The Need for Stream Vegetated Buffers:
What Does the Science Say?

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Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Wildlife and Wildlife Habitat

Introduction

Riparian areas and wetlands make up approximately 4% of the Montana's landscape—yet about one-third of our wildlife species depend upon these areas for some part of their life cycle (Montana's Comprehensive Fish and Wildlife Conservation Strategy [MCFWCS], 2005). Unplanned commercial and residential development can cause significant, permanent loss and degradation of this critical wildlife habitat. One of the most effective tools available to local governments interested in minimizing habitat loss and degradation is to set back structures and protect streamside buffers with native vegetation (hereafter referred to as "building setbacks with vegetated buffers"). In order to use this tool, however, decision makers and citizens alike must understand the science behind different buffer widths.

Protecting wildlife is one of the important functions of building setbacks with vegetated buffers. This report—which is focused on wildlife and wildlife habitat—is part of a series of reports that summarizes the science behind buffers. Because it is the vegetative buffer portion of the tool that provides wildlife with critical habitat, scientific studies examining this issue focus on the portion of this tool with native vegetation. For more information on how building setbacks relate to vegetated buffers, see page 3.

This series of reports on the science behind vegetated buffers includes two other reports on other key elements of stream protection: water quality and fisheries:

- *Part I: Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Water Quality*; and
- *Part II: Scientific Recommendations on the Size of Stream Vegetated Buffers Needed to Protect Fish and Aquatic Habitat.*

Local Governments and Wildlife

Local governments have the authority to protect wildlife and wildlife habitat under growth policies, subdivision regulations, and other land use planning statutes.

Each of these reports is designed to explain the science behind one of the many functions provided by vegetated buffers found along streams. Other topics for this series are currently being considered because building setbacks and vegetated buffers should also consider floodplains and seasonal water levels, stream migration corridors, density of development adjacent to the riparian corridor, and other factors.

Building Setbacks and Vegetated Buffers

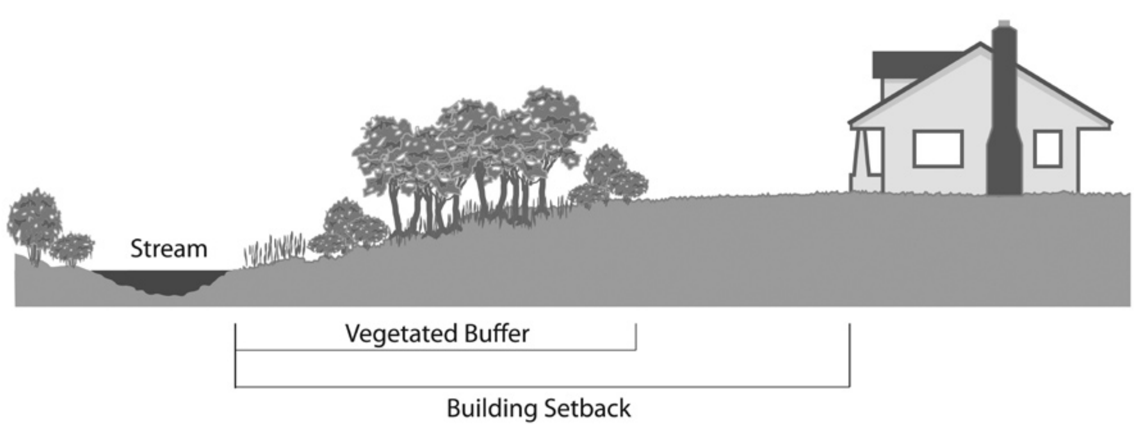
In order to understand setbacks and buffers, it is important to understand the following concepts:

Building setbacks or "no build areas" are the distance from a stream's ordinary high water mark to the area where new structures and other developments (such as highly polluting land uses—including roads, parking lots, and waste sites) are allowed.

Vegetated Buffers are not an additional area, but rather the portion of the building setback that is designated to remain undisturbed. These buffers are areas where all native vegetation, rocks, soil, and topography are maintained in their natural state or enhanced by additional planting of native plants. Lawns should not be considered part of the vegetated buffer. With their shallow roots, lawns are not particularly effective at absorbing and retaining water, especially during heavy rains. Consequently, they do not significantly filter out water pollutants. They can also be a major source of fertilizers and pesticides—substances that should be prevented from entering our streams and rivers.

How much space should be placed between a building and a vegetated buffer? The building setback should be wide enough to prevent degradation of the vegetated buffer. As an example, most families use the area between their home and the vegetated buffer for lawns, play areas, swing sets, picnic tables, vegetable gardens, landscaping, etc. As a result, the building setback should extend at least 25–50 feet beyond the vegetated buffer (Wenger 1999). A smaller distance between a building and a vegetated buffer, such as 10 feet, will most likely guarantee degradation of the vegetated buffer. A larger distance between structures and a vegetated buffer is recommended if the:

- River has a history of meandering; the setbacks should ensure that people and homes will not unwittingly be placed too close to the river's edge, in harm's way.
- Vegetated buffer is narrower than scientific studies recommend; a larger building setback can help protect water quality, fisheries, and aquatic habitat.
- Land is sloped and runoff is directed toward the stream (the steeper the slope, the wider a buffer or setback should be).
- Land use is intensive (crops, construction, development).
- Soils are erodible.
- Land drains a large area.
- Aesthetic or economic values need to be preserved.
- Wildlife habitat needs to be protected.
- Landowners desire more privacy.



Vegetated Buffers, Wildlife, and Wildlife Habitat

Perhaps the best-known reason for protection of streamside areas is their importance for wildlife and wildlife habitat. Over half of Montana's wildlife species are known to use or frequent riparian areas or wetlands. And at least 196 of our state's wildlife—approximately one-third of our wildlife species—are considered "riparian/wetland obligates," which means they *depend* upon these areas for some part of their life cycle (MCFWCS, 2005).

Riparian areas make up approximately 3% of the state's landscape; wetlands make up almost 1% of the state. Together, this small piece of Montana supports the habitat required to sustain an incredible number of species, including:

Amphibians and Reptiles. Streamside buffers and wetlands provide essential breeding, foraging, and over-wintering habitat for Montana's 16 native amphibians (salamanders, frogs, and toads), 3 turtles, and at least 7 of Montana's snakes (MCFWCS, 2005). Because many of these species (especially amphibians and turtles) are not very mobile, all of their habitat requirements need to be found in a relatively confined area. Streamside habitats provide drinking water; abundant food, such as aquatic plants, invertebrates (e.g. insects, spiders, snails, and worms), and small fish; dense vegetation and woody debris for cover; reproductive sites, which may necessitate having habitat for aquatic larvae; and a moist microclimate and a well-developed litter layer that provides numerous benefits, including protection during hot, dry summers.

Birds. Montana's riparian areas and wetlands provide breeding and nesting areas for at least 52% of Montana's breeding bird species (134 of Montana's 259 breeding birds) (Montana Audubon, unpublished data, 2006). Birds are diverse in their food and habitat needs—and streams and their associated vegetation provide essential requirements in a small area. As an example, riparian areas provide habitat for birds that primarily eat: flying insects (e.g. flycatchers, kingbirds, swallows, wrens); bark-dwelling insects (e.g. woodpeckers, chickadees, creepers); insects living on plants (e.g. vireos, orioles, thrush, and warblers are called gleaners), ground-dwelling insects and other invertebrates (e.g. towhees, sparrows); aquatic insects and/or aquatic plants (e.g. ducks, American Dipper); fish (e.g. Osprey, eagles, Belted Kingfishers, herons, mergansers); small birds and mammals (hawks and owls); and plant seeds, fruits, berries, buds, etc. (e.g. Ruffed Grouse, sparrows, waxwings). These birds nest on the ground (e.g. Ruffed Grouse, shorebirds, most ducks); in dense shrubs and willows (e.g. cuckoos, Rufous Hummingbirds, flycatchers, vireos, thrush, warblers, sparrows); in tree cavities (e.g. woodpeckers, smaller owls, cavity-nesting ducks, nuthatches, some wrens and swallows); in large trees, including snags (e.g. eagles, Osprey, hawks, larger owls, herons, flycatchers, vireos, orioles, warblers); and in tunnels dug into eroding banks (e.g. Bank Swallows, Belted Kingfishers). In addition to providing habitat for resident birds, Montana's stream and river corridors also provide essential food and resting areas for numerous and diverse migrating birds.

Mammals. Riparian areas provide important seasonal or year-round habitat for at least 56 of Montana's mammals, including 36 species of small mammals (rodents, rabbits, and shrews), 8 bats, 7 carnivores (otter, weasels, raccoons, and skunks), and 4 ungulates (white-tailed and mule deer, moose, and pronghorn) (MCFWCS, 2005). Mammals use streamside habitat for food, cover, protected access to water, travel routes, and relief from hot dry summers and cold, snowy winters. Small mammals use streamside areas for many of the reasons described under amphibians and reptiles above. Montana's bat species eat flying insects, which are abundant near streams; they also roost in these areas because of the

availability of cavities, crevices, and/or foliage. Carnivores benefit from the diverse wildlife found in vegetative buffers (providing plentiful food sources), as well as from specific habitat components, such as hollow trees, snags, and debris piles for resting and denning sites (used by otter, bobcat, mink, marten, and many small mammals). Moose are the ungulate species most associated with streams and wetlands because of their dependence on riparian vegetation as food.

For the purpose of this publication, "wildlife" means terrestrial vertebrates: amphibians, reptiles, birds, and mammals. Table II lists the streamside buffer requirements for various species of Montana wildlife. Appendix I summarizes individual scientific studies about the buffer requirements for specific species, groups of species (amphibians, reptiles, etc.), different types of habitats (e.g. cottonwood forests, shrub-steppe, forests), and specific issues related to wildlife use of stream vegetated buffers (e.g. travel corridor use, wildlife response to disturbance, nest predation/parasitism).

Specific Habitat Components of Wildlife

As mentioned above, streamside buffers must provide enough room for wildlife to take shelter, find food, successfully raise young, and hide from and avoid predators. As more and more people choose to build homes or otherwise utilize the land next to Montana's streams and rivers, the pressures to develop these areas are increasing—often to the detriment of Montana's wildlife. Specific ways that streamside buildings and their associated development can impact wildlife habitat are described below:

Dense Cover and Woody Debris. Many wildlife species depend on dense cover to nest in, raise young, and hide or escape from predators. Removing riparian vegetation, including mowing or manicuring the landscape, removes an important habitat component for certain species. Snags and large, down logs also provide nesting and denning sites, places to rear young, and other significant habitat for amphibians, reptiles, some birds, and many small mammals.

Habitat Fragmentation. Land development commonly leads to habitat fragmentation. Building homes, roads, and associated development in riparian corridors creates a patchwork of habitat fragments, many of which are isolated from one another. The size of the remaining habitat patches significantly influences the diversity of wildlife species in an affected area. This is caused in part because wildlife species respond differently to human disturbance and development: those that do not adapt well to disturbance, avoid developed areas; those that become habituated or attracted to these areas, thrive. As an example, American Robin, European Starling, raccoons, and deer tend to thrive in fragmented habitat. Small, isolated patches of habitat can also be important to migrating birds when they are looking for short-term places to find food and shelter. Species that do not adapt well to habitat fragmentation are often rare or habitat specialists, including ground-feeding and ground-nesting birds, herons, eagles, Osprey, Pileated Woodpeckers, and many songbirds (flycatchers, vireos, American Redstart and other warblers, Spotted Towhee, and more). Additionally, less mobile wildlife, as a group, (amphibians, reptiles, and some small mammals) do not adapt well to habitat fragmentation because even small areas of unsuitable habitat (e.g. roads and parking lots) are difficult—and oftentimes impossible—to cross.

Narrow riparian strips are also known to attract a disproportionate number of predators, including predatory mammals (e.g. domestic cats, raccoons, skunks), egg-eating birds (e.g. crows, magpies), and nest parasitizers (Brown-headed Cowbirds). Brown-

headed Cowbirds, found in mid to low elevations throughout Montana, feed in open areas and are often associated with livestock (horses or cattle) and houses with bird feeders. Cowbirds never build their own nests. Instead, they parasitize the nests of other birds by laying their eggs in other birds' nests. The host birds may abandon the nest, or raise the young cowbirds, usually raising fewer or none of their own young. In the West, cowbirds strongly prefer riparian deciduous forests near agricultural or residential areas; large, intact forests have significantly lower rates of parasitism than fragmented forests.

While narrow buffers offer habitat benefits to many species, most wildlife—especially birds and larger mammals—depend upon riparian areas that are much wider (see *Table II* and *Appendix I*).

> Local governments interested in determining the wildlife species using riparian areas in their jurisdiction should contact their local office of Montana Fish, Wildlife & Parks and the Montana Natural Heritage Program located in Helena (406-444-5354 or http://nhp.nris.mt.gov/).

Habitat Complexity. The more complex the vegetation, in both species of plants and diverse heights, the larger the variety of wildlife found. As an example, a healthy cottonwood forest, with 60-foot and taller trees in the canopy, can have pine, dogwood, green-ash, and box elder in the mid-story layer, and a variety of shrubs, grasses, and other plants closer to the ground. This diverse riparian habitat has the "greatest concentration of plants and animals in Montana" (MCFWCS, 2005). Although riparian areas can also be naturally dominated by pine trees, shrubs, grasslands, and other vegetation, these other habitat types support different and fewer species of wildlife than cottonwood gallery forests. One reason why many biologists are concerned about the spread of Russian olive in eastern Montana is that this plant species is shade-tolerant and will slowly out-compete and replace cottonwoods, green ash, and other native species over time. A Russian olive monoculture does not benefit as many wildlife species as a healthy, diverse native cottonwood forest.

About This Report—Methods Used

This report summarizes the recommendations of 83 scientific studies that tested how various stream vegetated buffers protect wildlife and wildlife habitat (see *Appendix I*). These scientific studies were reviewed by the authors of 4 review publications; two additional sources provided supplemental information on Montana-specific wildlife species. Please note that the information in this report was taken from the text and tables of these 6 publications—and that in most cases the original studies were not reviewed in this report.

The 4 review publications are:

Fischer, R.A. 2000. Width of riparian zones for birds. EMRRP Technical Notes Collection (TN EMRRP-SI-09), U.S. Army Corps of Engineer Research and Development Center, Vicksburg, MS. 7 pp.

Fischer, R.A. C.O. Martin, and J.C. Fischenich. 2000. Improving riparian buffer strips and corridors for water quality and wildlife. International Conference on Riparian Ecology and management in Multi-Land Use Watersheds. American Water Resources Association. August 2000. 7 pp.

Knutson, K.L., and V.L. Naef. 1997. Management recommendations for Washington's priority habitats: riparian. Wash. Dept. Fish and Wildlife, Olympia, WA. 181 pp.

Wenger, S.J. 1999. A review of the scientific literature

on riparian buffer width, extent and vegetation. Athens: Institute of Ecology Office for Public Service and Outreach, University of Georgia. 59pp.

Information from two additional publications is also included in this report:

Ellis, Janet, and Jim Richard. 2008. A Planning Guide for Protecting Montana's Wetlands and Riparian Areas. Revised edition. Bozeman, MT, Montana Watercourse, publication MTW-01-03. 105 pp.

This publication is included because it contains information on stream vegetated buffer requirements of several Montana wildlife species that were not found in the above review publications (e.g. otter, bobcat, and cavity nesting ducks).

Schwab, Nathan A. 2006. Roost-site selection and potential prey sources after wildland fire for two insectivorous bat species (*Myotis evotis* and *Myotis lucifugus*) in mid-elevation forests of western Montana. 89 pp.

This publication is included because it contains original scientific research on stream vegetated buffer requirements of two Montana bats with fairly wide distribution. No information on bats appeared in the above review publications.

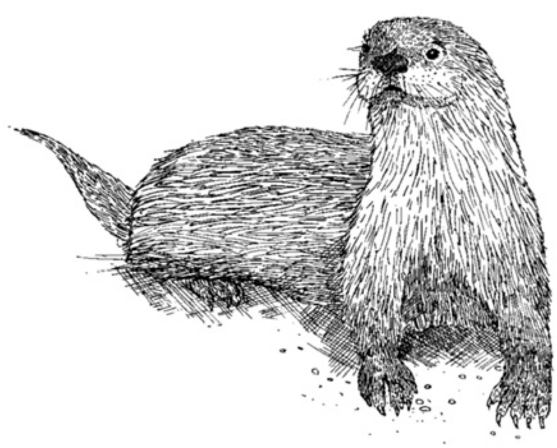
Appendix II contains the original references cited in the 6 publications described above, allowing individuals using Appendix I to see the full title of all original references, as well as have sufficient information to access all references, if necessary.

Summary of Recommendations of Scientific Studies

The future of Montana's wildlife depends on the thoughtful planning and protection of vegetated buffers along our streams. Streamside areas only represent a small part of our state—less than 4%. Yet more than half of our state's wildlife use these areas for food; protected access to water; cover; resting areas during migration; travel routes; relief from hot dry summers or cold, snowy winters; and breeding areas. Consequently,:

Scientific studies recommend that, in order to protect wildlife and wildlife habitat, 300-foot (100-meter) stream vegetated buffers be maintained. Certain wildlife species need a larger vegetated buffer.

This recommendation is drawn from the conclusions of 6 publications that reviewed a total of 83 separate scientific studies on wildlife, wildlife habitat, and stream vegetated buffers. Specific conclusions



and recommendations by the authors in these review articles are quoted in Table I.

In order to better understand the conclusions found above, Table II summarizes the scientific information for various wildlife species and groups of species found in Montana. Additionally, Appendix I contains study-specific information for all 83 scientific studies reviewed in the 6 publications featured in this report. It should be noted that many of these studies found in Appendix I underwent extensive peer review before they were published in a professional journal or report of a scientific government agency. Because the habitat needs of different wildlife are so diverse, the summarized studies show a range of buffer widths. It would be very costly to duplicate these studies on a case-by-case basis; hence the recommendations given here are intended to be protective in most situations, based on the findings of a wide range of studies. If localized information on area conditions is available (vegetation maps, floodplain maps, etc.), this information can also be used to ensure that buffers more accurately fit local conditions.

Table I. A summary of the specific conclusions and recommendations of six publications on the size of vegetated buffers needed for wildlife and wildlife habitat protection. All authors emphasized that different species of wildlife require different vegetated buffer widths.

Ellis and Richards 2008	"While narrow buffers offer habitat benefits to many species, most wildlife—especially birds and larger mammals—depend upon riparian areas that are a minimum of 300 feet wide."
Fischer 2000	"If avian habitat is a management objective, managers should consider managing for riparian zones that are at least 100 m [328 feet] wide."
Fischer et al 2000	"Recommended widths for ecological concerns in buffer strips typically are much wider than those recommended for water quality concerns, often exceeding 100 m [328 feet] in width. These recommendations usually apply to either side of the channel in larger river systems and to total width along smaller streams where the canopy is continuous across the channel."
	"Management for long, continuous buffer strips rather than fragments of greater width should also be an important consideration."
Knutson and Naef 1997	The mean width of all wildlife studies reviewed indicate that 88 meters (287 feet) is required to protect wildlife habitat.
Schwab 2002	"Our research shows the average minimum distance between [bat] roost sites and perennial water to be 90 meters [295 feet]."
Wenger 1999	"While narrow buffers offer considerable habitat benefits to many species, protecting diverse terrestrial riparian wildlife communities requires some buffers of at least 100 m (~300 ft)."
	"[H]owever, 300 ft wide buffers are not practical on all streams in most areas. Therefore, minimum riparian buffer width should be based on water quality and aquatic habitat functions. . . . In addition, at least a few wide (300–1000 ft/~90–300 m) riparian corridors and large blocks of upland forest should be identified and targeted for preservation."

Table II. Summary of stream vegetated buffer widths needed by various Montana wildlife. Research shows that the following buffer widths are needed to support different species of Montana wildlife. This table was compiled using information from the scientific studies reported in Appendix I from the 6 publications featured in this report.

Wildlife dependent on wetlands or watercourses	Desired Buffer Width in feet
Elk caving grounds, Sandhill Crane nests	1000 +
Great Blue Heron nest	820–985
Cavity nesting ducks	600
Bald Eagle nests	400–1,320
Pileated Woodpecker, fisher, mink	330–600
Large mammals, bobcat, red fox, otter, muskrat, dabbling ducks	330
Wood Duck	250–600
Osprey, pine marten	200–330
Spruce Grouse	200
Amphibians and reptiles, Belted Kingfisher, beaver	100–330
Small mammals	40–300
Hairy Woodpecker	130
Deer, Ring-necked Pheasant	75
Mourning Dove, Downy Woodpecker	50
Songbirds	**50–660**
American Redstart, Spotted Towhee	660
Warbling Vireo	300
Brown Creeper, Ruby-crowned Kinglet, Swainson's Thrush	200
Red-eyed Vireo, Brown Thrasher	130
Black-capped Chickadee, White-breasted Nuthatch	50

Appendix I.

Summary of 83 Scientific Studies Conducted on the Size of Stream Vegetated Buffers Needed to Protect Wildlife and Wildlife Habitat. The information in this table was taken from the text and tables of the 6 publications described above. This table summarizes (1) the purpose of the buffer that was tested in a scientific study (Vegetated Buffer Function); (2) the size (in meters and feet) of the vegetated buffer tested; (3) the author of the scientific study who tested the buffer's function and size; and (4) the name of the publication where the scientific study was summarized. As much as possible, the studies in this table are listed from most protective to least protective. Note that information about fish and instream habitat appears in Part II of this report series, *Scientific Recommendations on the Size of Stream Vegetated Buffer Needed to Protect Fish and Aquatic Habitat*.

GENERAL WILDLIFE HABITAT				
Vegetated Buffer Function	**Distance from stream in meters**	**Distance from stream in feet**	**Author of Original Scientific Study**	**Name of Review Article**
General wildlife habitat	100-year floodplain plus additional upland area on at least one side	100-year floodplain plus additional upland area on at least one side	Schaefer and Brown 1992	Wenger 1999
General wildlife habitat—flooding needed to regenerate cottonwood forests in western United States (dam-altered flows cause problems)	100-year flood-plain	100-year flood-plain	Poff et al 1977	Wenger 1999
General wildlife habitat	61	200	Zeigler 1992	Knutson and Naef 1997
Riparian vegetation width in shrub-steppe	50–100	164–328	Medin and Clary 1991	Knutson and Naef 1997
General wildlife habitat—maintain plant diversity	≥30	≥100	Spackman and Hughes 1995	Fischer et al 2000
General wildlife habitat—depends on species	9–201	30–660	Johnson and Ryba 1992	Knutson and Naef 1997; Castelle et al 1994
Width of riparian vegetation—depends on species	20–50	66–164	Strong and Bock 1990	Knutson and Naef 1997

REPTILES AND AMPHIBIANS				
	Meters	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
Reptiles and amphibian habitat	≥165	≥540	Semlitsch 1998	Fischer et al 2000
Reptile and amphibian habitat	≥135	≥443	Buhlmann 1998	Fischer et al 2000
Reptiles and amphibian habitat	100	328	Burbrink et al 1998	Wenger 1999; Fischer et al 2000
Reptiles and amphibian habitat —buffer requirements for riparian-dependent species	75–100	246–328	Gomez and Anthony 1996	Wenger 1999
Reptiles and amphibian habitat—riparian-dependent species more numerous with buffer width in mature vegetation	30–95	100–312	Rudolph and Dickson 1990	Knutson and Naef 1997
Reptiles and amphibian habitat—Full complement of reptiles and amphibians	≥30	≥100	Rudolph and Dickson 1990	Knutson and Naef 1997; Fischer et al 2000
Reptile habitat—requirements for certain fresh water turtles	275	902	Burke and Gibbons 1995	Wenger 1999

REPTILES AND AMPHIBIANS (continued)				
	Meters	Feet	Author of Original Scientific Study	Name of Review Article
Amphibian habitat—Distance needed for sediment control, important to maintaining habitat quality for Cascade torrent, Columbia torrent, Dunn's, and Van Dyke's salamanders	31–88	100–289	Erman et al 1977, Lynch et al 1985, Terrell and Perfetti 1989, Johnson and Ryba 1992	Knutson and Naef 1997; Fischer et al 2000
Amphibian habitat—Distance needed for woody debris recruitment, an important habitat component for Cascade torrent, Columbia torrent, Dunn's, and Van Dyke's salamanders	31–55	100–180	Bottom et al 1983, Harmon et al 1986, Murphy and Koski 1989, McDade et al 1990, Van Sickle and Gregory 1990	Knutson and Naef 1997

BIRDS				
	Meters	Feet	Author of Original Scientific Study	Name of Review Article
General Bird Habitat				
Bird habitat—size of naturally vegetated buffer needed to retain full complement of birds	125	410	Croonquist and Brooks 1993	Knutson and Naef 1997
Bird habitat—Full compliment of birds present; avian richness declines after this point in cottonwood floodplains	127	417	Sedgewick and Knopf 1986	Knutson and Naef 1997
Bird habitat—riparian buffer size needed to include 90% of bird species along mid-order streams	150–175	492–574	Spackman and Hughes 1995	Wenger 1999; Fischer 2000; Fischer et al 2000
Bird habitat—Riparian buffers should be at least this wide to provide some nesting habitat for sensitive species	100	328	Keller et al 1993	Fischer 2000
Bird habitat—recommended buffer for birds	75–200	246–656	Jones et al 1988	Knutson and Naef 1997
Bird habitat—minimum buffer width recommended for bird species	70	230	Kinley and Newhouse 1997	Wenger 1999
Bird habitat—bottomland hardwood strips can support diverse bird populations; at least 500 m needed to maintain complete avian community	50–500	164–1640	Kilgo et al 1998	Wenger 1999; Fischer 2000; Fischer et al 2000
Bird habitat—buffer distance needed to provide sufficient breeding habitat for area-sensitive forest birds.	≥100	≥328	Mitchell 1996	Fischer 2000; Fischer et al 2000
Bird habitat—45% reduction in birds in agricultural areas if no fencerows are within this distance of a stream	100	328	Croonquist and Brooks 1993	Knutson and Naef 1997
Bird habitat—bird species sensitive to disturbance did not occur unless an undisturbed corridor this wide was present	25	82	Croonquist and Brooks 1993	Knutson and Naef 1997

	Meters	Feet	Author of Original Scientific Study	Name of Review Article
General Bird Habitat (continued)				
Bird habitat—depends on species	50–1,600	164–5,250	Richardson and Miller 1997	Fischer et al 2000
Bird forest habitat—minimum riparian width to sustain forest-dwelling birds	≥60	≥200	Darveau et al 1995	Knutson and Naef 1997; Fischer 2000; Fischer et al 2000
Bird forest habitat—riparian buffers along headwater streams provide the most benefit for forest-associated bird species if they are >40 m	>40	>131	Hagar 1999	Fischer 2000; Fischer et al 2000
Bird habitat—Narrow stream corridors (15–50 m) can help maintain bird diversity even though they are insufficient for protecting forest-dependent species	15–50	50–164	Thurmond et al 1995	Wenger 1999
Bird forest habitat—small buffers will benefit some edge-dwelling songbirds	15–23	49–76	Triquet et al 1990	Wenger 1999
Birds-Nest Predation				
Nest predation—Brown-headed Cowbird—distance cowbirds penetrate from stream opening	240	787	Gates and Giffin 1991	Knutson and Naef 1997
Nest predation—riparian buffers this wide reduce edge-related nest predation.	≥150	≥490	Vander Haegen and deGraaf 1996	Fischer et al 2000
Nest predation—riparian buffer width that reduces nest predation	100	328	Temple 1986	Knutson and Naef 1997
Waterfowl				
Wood Duck—maximum distance from water where Wood Ducks will nest	350	1148	Gilmer et al 1978	Knutson and Naef 1997
Wood Duck—nest within this distance	200	656	Lowney and Hill 1989	Knutson and Naef 1997
Wood Duck—nesting distance	183	600	Grice and Rogers 1965	Knutson and Naef 1997
Wood Duck—nesting where woody/herbaceous cover is between 50-75%	183	600	Sousa and Farmer 1983	Knutson and Naef 1997
Wood Duck—average distance of wood duck nests from water	80	262	Gilmer et al 1978	Knutson and Naef 1997
Lesser Scaup prefer nesting habitat within this distance in emergent vegetation	50	164	Allen 1986a	Knutson and Naef 1997
Harlequin—stream buffer needed to maintain harlequin nests	50	164	Cassirer and Groves 1990	Knutson and Naef 1997
Harlequin—large woody debris use by loafing Harlequin Ducks	30+	100+	Murphy and Koski 1989	Knutson and Naef 1997
Cavity nesting ducks (includes Wood Ducks, goldeneye, Buffelhead, and Hooded Merganser)	182	600	Cohen 1997	Ellis and Richard 2008

	Meters	Feet	Author of Original Scientific Study	Name of Review Article
Birds—Species Information (Birds generally listed in taxonomic order)				
Waterfowl				
Dabbling ducks (includes Pintail, teal, widgeon, Mallards, shoveler, etc.)	100	330	Cohen 1997	Ellis and Richard 2008
Grouse and their Allies				
Ring-necked Pheasant—buffer size needed in Eastern Washington	23	75	Mudd 1975	Knutson and Naef 1997
Spruce Grouse—minimum buffer width to sustain	60	197	Darveau et al 1995	Knutson and Naef 1997
Herons and Cranes				
Great Blue Heron—minimum buffer zone around peripheries of Great Blue Heron colonies	250–300	820–984	Bowman and Siderius 1984, Kelsall 1989, Vos et al 1985	Knutson and Naef 1997
Great Blue Heron—nesting	250–300	820–984	Parker 1980, Short and Cooper 1985, Vos et al 1985	Knutson and Naef 1997
Great Blue Heron—recommended disturbance-free zone around heron nesting areas	250	820	Short and Cooper 1985	Knutson and Naef 1997
Great Blue Heron—nesting	250	820	Short and Cooper 1985	Knutson and Naef 1997
Great Blue Heron—recommended disturbance-free zone around heron feeding areas	100	328	Short and Cooper 1985	Knutson and Naef 1997
Sandhill Cranes—recommended disturbance-free zone around Sandhill Crane nesting areas	400	1,312	Schlorff et al 1983	Knutson and Naef 1997
Raptors				
Osprey nesting—recommended hiking trail buffer near Osprey nests	91	300	Zarn 1994	Knutson and Naef 1997
Osprey nesting—no cut zone	61	200	Zarn 1974, Westall 1986	Knutson and Naef 1997
Bald Eagle—distance from human activity at which nesting eagles are disturbed	400	1,320	Montana Bald Eagle Working Group 1991	Ellis and Richard 2008
Bald Eagle—recommended buffer for eagle perch areas with little screening	250–300	820–984	Stalmaster 1980	Knutson and Naef 1997
Bald Eagle—distance from human activity at which feeding eagles are disturbed	200	656	Skagen 1980	Knutson and Naef 1997
Bald Eagle—average distance of successful Bald Eagle nests from human disturbance	119	396	Grubb 1980	Knutson and Naef 1997
Bald Eagle—eagles nest within this distance of water	100	328	Small 1982	Knutson and Naef 1997

	Meters	Feet	Author of Original Scientific Study	Name of Review Article
Raptors (continued)				
Bald Eagle—recommended leave strip for Bald Eagles along shoreline of major feeding areas	75–100	246–328	Stalmaster 1980	Knutson and Naef 1997
Bald Eagle—most Bald Eagles perch within this distance of water during daylight hours	50	164	Stalmaster 1980	Knutson and Naef 1997
Doves, Cuckoos, and Kingfishers				
Mourning Dove	15	50	Mudd 1975	Knutson and Naef 1997
Belted Kingfisher roosts	30–60	100–197	Prose 1985	Knutson and Naef 1997
Yellow-billed Cuckoo—100 meter minimum riparian buffer width for breeding habitat; stream length must be at least 300 meters	≥100	≥328	Gaines 1974	Knutson and Naef 1997; Fischer 2000
Yellow-billed Cuckoo—buffer required by cuckoo	91	300	Gaines and Laymon 1984	Knutson and Naef 1997
Woodpeckers				
Downy Woodpecker	25	82	Stauffer and Best 1980	Knutson and Naef 1997
Downy Woodpecker	15	50	Cross 1985	Knutson and Naef 1997
Hairy Woodpecker—minimum mean width supporting breeding populations of Hairy Woodpeckers	40	133	Stauffer and Best 1980	Knutson and Naef 1997
Northern Flicker avoided isolated forest patches farther than this distance from water	124	407	Gutzwiler and Anderson 1987	Knutson and Naef 1997
Pileated Woodpecker—nesting	150–183	492–600	Conner et al 1975, Schroeder 1983	Knutson and Naef 1997
Pileated Woodpecker—most Pileated Woodpeckers nest within this distance of water	150	492	Conner et al 1975, Schroeder 1983	Knutson and Naef 1997
Pileated Woodpecker—nesting within this distance of stream	100	328	Small 1982	Knutson and Naef 1997
Pileated Woodpecker do not use buffers this size	15–23	50–75	Triquet et al 1990	Knutson and Naef 1997
Songbirds (Songbirds that are "Neotropical Migrants" breed in Montana but winter in the neotropics (Central and South America))				
Neotropical Migrants were more abundant in riparian corridors wider than 100 meters	≥100	≥328	Triquet et al 1990	Knutson and Naef 1997; Fischer 2000; Fischer et al 2000
Neotropical Migrants—distance needed to maintain functional assemblages of 6 common neotropical migratory birds	≥100	≥328	Hodges and Krementz 1996	Knutson and Naef 1997; Wenger 1999; Fischer 2000; Fischer et al 2000

	Meters	Feet	Author of Original Scientific Study	Name of Review Article
Songbirds (continued)				
Neotropical Migrants—minimum buffer width needed to support area-sensitive neotropical migrant birds in forest/agricultural areas	100	328	Keller et al 1993	Knutson and Naef 1997; Wenger 1999; Fischer et al 2000
Neotropical Migrants—sensitive species of flycatchers and warblers inhabit buffers of this size	75–150	246–492	Smith and Schaefer 1992	Wenger 1999
Neotropical Migrants—minimum riparian width to sustain neotropical migrants (many neotropical birds will not inhabit narrower buffers)	$\geq$50	164	Tassone 1981	Knutson and Naef 1997; Fischer 2000
Neotropical Migrants—significant increases in bird densities found for several species	50–100	164–328	Hodges and Krementz 1996	Wenger 1999
Neotropical Migrants—narrow buffer supports more songbirds than no buffer near agricultural fields	50	164	Keller et al 1993	Wenger 1999
Neotropical Migrants—sensitive species of flycatchers and warblers *missing* from buffers of this size	20–60	66–197	Smith and Schaefer 1992	Wenger 1999
Neotropical Migrants do not use buffers this size	15–23	50–75	Triquet et al 1990	Knutson and Naef 1997
Warbling Vireo—average distance of warbling vireo nests from water	90	295	Gilmer et al 1978	Knutson and Naef 1997
Red-eyed Vireo—minimum mean width supporting breeding populations of red-eyed vireos	40	133	Stauffer and Best 1980	Knutson and Naef 1997
Black-capped Chickadee	15	50	Cross 1985	Knutson and Naef 1997
White-breasted Nuthatch	17	57	Stauffer and Best 1980	Knutson and Naef 1997
Brown Creeper—minimum buffer width to sustain	60	197	Darveau et al 1995	Knutson and Naef 1997
Ruby-crowned Kinglet—minimum buffer width to sustain	60	197	Darveau et al 1995	Knutson and Naef 1997
Swainson's Thrush—minimum buffer width to sustain	60	197	Darveau et al 1995	Knutson and Naef 1997
Brown Thrasher	100	330	Cohen 1997	Ellis and Richard 2008
American Redstart—minimum mean width to support breeding populations of American Redstarts	200	656	Stauffer and Best 1980	Knutson and Naef 1997
Spotted Towhee—minimum mean width to support breeding populations of Spotted Towhees	200	656	Stauffer and Best 1980	Knutson and Naef 1997
Red-winged Blackbird—foraging distance from nests in wetlands	200	656	Short 1985	Knutson and Naef 1997

MAMMALS				
	Meters	**Feet**	**Author of Original Scientific Study**	**Name of Review Article**
General Habitat for Mammals				
Mammal habitat	≥50	≥164	Dickson 1989	Fisher et al 2000
Large mammals—recommended riparian buffer for large mammals	100	328	Jones et al 1988	Knutson and Naef 1997
Small mammals—recommended riparian buffer width for small mammals	67–93	220–305	Jones et al 1988	Knutson and Naef 1997
Small mammals—diversity and species composition similar to undisturbed sites	67	220	Cross 1985	Wenger 1999
Small mammals—no small mammal species lost	12–70	39–230	Cross 1985	Knutson and Naef 1997
Mammal—Species Information				
Dusky shrew—food and cover	183	600	Clothier 1955	Knutson and Naef 1997
Bats—average minimum distance between roost sites and streams for two Montana bat species	90	295		Schwab 2002
Beaver—majority of foraging	100	328	Allen 1983	Knutson and Naef 1997
Beaver foraging: 30 meters = 90% foraging distance for beaver; 100 meters = maximum foraging distance (but 200 meters has been reported)	30–100	100–328	Allen 1983, Hall 1970	Knutson and Naef 1997
Muskrat	100	330	Cohen 1997	Ellis and Richard 2008
Carnivores				
Mink will not use areas farther than 200 meters from water	200	656	Melquist et al 1981	Knutson and Naef 1997
Mink—riparian buffer needed for dens, cover, and forage	100	328	Melquist et al 1981, Allen 1986b	Knutson and Naef 1997
Mink—buffer area of optimum cover and forage habitat	100	328	Allen 1986b	Knutson and Naef 1997
Otter	100	330	Cohen 1997	Ellis and Richard 2008
Fisher travel corridor—needed on each side of stream to provide a 600 foot travel corridor in mature uncut basins for fisher	91	300	Freel 1991	Knutson and Naef 1997
Fisher use	100	328	Small 1982	Knutson and Naef 1997
Pine Marten—vegetation within this distance used by marten as travel corridor and habitat	100	328	Small 1982	Knutson and Naef 1997
Pine Marten—food and cover	61	200	Spencer 1981	Knutson and Naef 1997

	Meters	Feet	Author of Original Scientific Study	Name of Review Article
Carnivores (continued)				
Pine Marten—provides travel corridors for marten when buffers are on both sides of streams in mature uncut basins (total buffer is 91 meters)	46	151	Freel 1991	Knutson and Naef 1997
Bobcat	100	330	Cohen 1997	Ellis and Richard 2008
Red fox—Vegetation within this distance used by red fox as travel corridor and habitat	100	328	Small 1982	Knutson and Naef 1997
Elk and Deer				
Elk calving grounds are usually within this distance of water	305	1,000	Thomas 1979	Knutson and Naef 1997
Deer and elk cover—distance hiding cover needed at 90% vegetative cover	61	200	Mudd 1975	Knutson and Naef 1997
Deer—riparian buffer needed by deer in eastern Washington	23	75	Mudd 1975	Knutson and Naef 1997

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